U. S. ARMY
TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

CRASH INJURY EVALUATION

PERSONNEL RESTRAINT SYSTEMS STUDY
CH-47 VERTOL CHINOOK

April 1964

Contract DA 44-177-AMC-888(T)

TRECOM Technical Report 64-4

prepared by :

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Excluding fire, failure of some portion of the occupant tie-down chain is the most significant factor contributing to the injury and death of personnel involved in survivable-type aircraft accidents. In an effort to eliminate this condition, considerable research has been devoted to the study of personnel restraint system concepts and their application to specific aircraft. This report, prepared by Aviation Safety Engineering and Research (AVSER), a division of the Flight Safety Foundation, Inc., under the terms of Contract DA 44-177-AMC-888(T), contains an evaluation of the crew and passenger restraint systems installed in the ~~CV-2~~ CA-47 aircraft, and proposes a practical and economical method of modifying these systems to provide increased occupant protection.

While views contained in this report have not been reviewed or approved by the Department of the Army, conclusions and recommendations contained herein are concurred in by this Command. However, responsibility for the implementation of these recommendations rests with the U. S. Army Aviation and Surface Materiel Command, St. Louis, Missouri, under whose auspices this program was prosecuted.

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PERSONNEL RESTRAINT SYSTEMS STUDY,

CH-47 VERTOL CHINOOK

Crash Injury Evaluation
AvCIR 62-26

Prepared by
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SUMMARY

This report presents detailed recommendations for the improvement of the personnel restraint systems in the U. S. Army CH-47 aircraft. The recommendations pertain primarily to the strengthening of existing components. The modifications proposed indicate the following strength improvements: (1) Cockpit - The crew's restraint system is increased from an 8-12G value to a 25-30G value; (2) Troop Compartment - The troop's lap-belt attachments are increased from a 10-15G value to a 22-28G value.

The above strength increases can be achieved with a weight increase of 7 pounds per aircraft and at a cost of approximately $300 per aircraft.

This report includes the following information:

1. Engineering - Strength analysis of proposed modifications.
2. Administrative - A cost and weight summary of proposed modifications.
3. Detailed engineering drawings are available as a supplement to this report.
    a. Parts Procurement or Manufacture - Drawings necessary for the procurement or manufacture of retrofit kits.
    b. Installation Procedure - Sufficient information is included in the drawings for installation of retrofit kits by Army personnel.

CONCLUSIONS

An analysis of the CH-47 personnel restraint systems reveals that:

1. The personnel restraint systems in the CH-47 are designed in accordance with, and in many instances exceed, the requirements of the applicable military specifications; however, they are still only about one-fourth of the desired strength in accordance with crash load data and human tolerance data.
2. The shoulder straps, inertia reel, and lap belts in the cockpit are designed for a 40G loading; however, human tolerance experiments indicate that this harness allows the lower torso to "submarine" under the belt during high longitudinal decelerations. The "submarining" can cause abdominal and spinal injuries.
3. Attaching the lap belts of the crew seats to basic structure does not appear to be the most practical method for strengthening the restraint system for the pilot and copilot; however, if the seats and supporting structure are reinforced, as indicated in the supplement to this report (published under separate cover) the strength analysis indicates that a 27G longitudinal load combined with a 13.5G lateral load can be sustained.
4. The troop commander's restraint is considerably improved, if a shoulder harness and lap-belt tie-down combination is added.
5. The troop commander's seat appears to be inadequate to sustain vertical loads in a survivable crash because of the manner in which it is attached to the aircraft structure.
6. The lap belts for the troops are designed for a 25G load, but the lap-belt anchorages are designed for only half this amount.
7. If the troop lap-belt anchorages are reinforced, as indicated in the supplement, they are calculated to sustain 25G loads in all directions.
8. The addition of shoulder straps for the troop seats is not practical unless the seats are redesigned and modified to withstand higher crash loads in accordance with known human limits.
9. The resistance of the crew seats to vertical loads would be improved if an energy-absorbing type of seat cushion is used. The use of this cushion would also reduce the loads on the spinal column of the seat occupant.

RECOMMENDATIONS

Based on the previous conclusions, it is recommended that:

1. The lap-belt tiedown as shown in Drawing HC-1-14 (in the supplement to this report) be added to the pilot's and copilot's restraint harnesses to alleviate the "submarine" effects.
2. The cockpit crew seats and supporting structure be reinforced as indicated in Drawing HC-1-10.
3. A shoulder harness be installed for the troop commander's seat as indicated in Drawing HC-1-15; and a lap-belt tiedown strap also be added as shown in Drawing HC-1-24.
4. The troop commander's seat be modified to increase its vertical load capacity during survivable crashes as noted in the Troop Commander's Compartment Section.
5. The troop lap-belt anchorages be reinforced as indicated in Drawing HC-1-30 (three sheets).
6. The troop seats be redesigned and/or modified to withstand higher crash loads in accordance with the known limits of human tolerance. The redesigned troop seats should also include a shoulder harness installation.
7. A mock-up evaluation of all proposed modifications in this report be conducted on one aircraft to ensure that no operational or maintenance problems exist.
8. An energy-absorbing type of seat cushion be installed in the crew seat buckets.

DESCRIPTION OF THE AIRCRAFT

GENERAL

Vertol's CH-47 "Chinook" is a twin-engine, tandem-rotor helicopter. It carries a crew of two and has accommodations for 33 troops and 1 troop commander, as shown in Figure 1. The mission of this aircraft is to increase the mobility of the Army in the field by the transportation of personnel, weapons, and cargo.

Some of the "Chinook's" crash-safe features are listed below:

1. All rotating parts of the power train are located outside the cabin.
2. Emergency water-landing capability is provided by the incorporation of large external pods along either side of the fuselage. The pods are constructed of metal honeycomb and are sealed and compartmented to provide buoyancy.
3. The fuel cells are also located in the external pods along either side of the fuselage, a feature which reduces the crash-fire hazard; however, this excellent design feature is compromised by the location of the forward landing gears. The landing gears can move aft during a crash and puncture the fuel cells.

Basic characteristics of the Chinook are listed in Table 1.

FUSELAGE

The fuselage structure consists of three principal subassemblies: the front section, extending from the nose to fuselage station 160, includes the flight compartment and a portion of the cargo compartment; the center section, which includes nearly all of the cargo compartment, extends aft to fuselage station 440; the rear section comprises the remainder of the fuselage, including the aft cargo door and ramp.

CREW COMPARTMENT

The cockpit has accommodation for a pilot and copilot in a standard seating arrangement with dual controls. The cockpit floor is elevated 13 inches above the level of the troop compartment floor.

A troop commander's or crew chief's folding-type seat is located just aft of the pilot and copilot's seats in the entry section to the crew compartment.

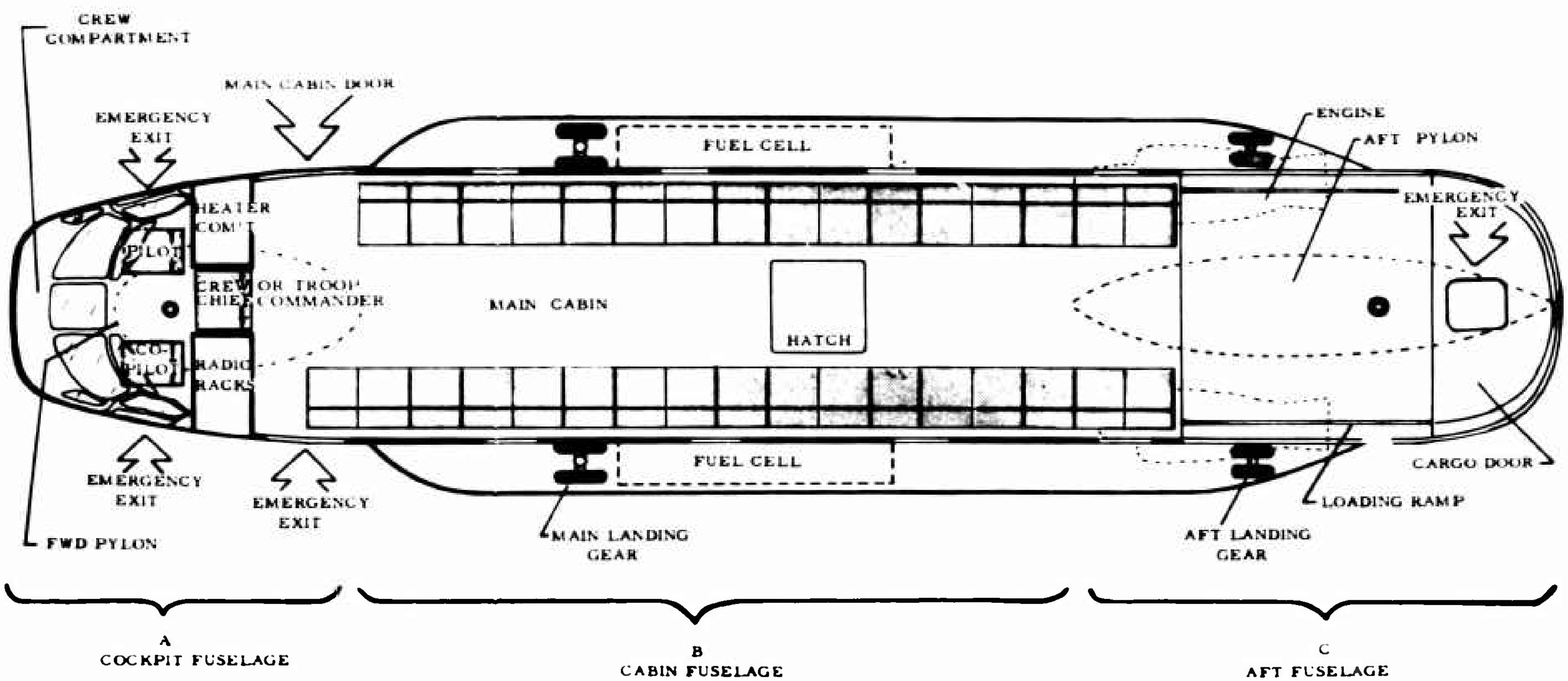

Figure 1. Cabin Layout.

TABLE 1
BASIC CHARACTERISTICS OF CH-47 "CHINOOK"

WEIGHTS		
Maximum take-off weight		33,000 lb
Operating weight	approx.	16,000 lb
Maximum payload	approx.	16,000 lb
Maximum fuel		16,228 lb
CARGO COMPARTMENT		
Length - main compartment		30.2 ft
Width - main compartment		7.5 ft
Height - main compartment		6.5 ft
PERSONNEL CAPACITY		
Number of fully equipped troops		34
Number of litter patients		24
POWER PLANTS		
Number/type		2/turbine
Manufacturer		Lycoming
Model		T 55-L-5
Take-off power, each		1940 hp

CARGO COMPARTMENT

The cargo compartment (cabin) is equipped with removable seats, cargo tie-downs, and installation provisions for 24 litters. The large rear cargo doors operate in two parts and provide access to the full floor width and the full ceiling height. The cabin is equipped with an emergency exit on the left side of the fuselage at the forward end of the cargo compartment. An emergency exit is also located in the aft cargo doors at the aft end of the cabin.

SCOPE OF THIS STUDY

The contract specifies that "the contractor shall study the feasibility and practicability of improving the attachment of seat belts and shoulder harness inertia reels for crew and passengers in all Army aircraft to provide for survivability in survivable crashes". In order to fulfill the feasibility and practicability aspects of this work statement, the scope is limited to the improvement and strengthening of the existing restraint harnesses, and all related anchorages, for loads in the forward and lateral directions only.

It was noted in the "Basic Concepts" report (reference 1) that the majority of shoulder straps and lap belts in the U. S. Army inventory are strong enough to restrain personnel up to known human limits; therefore, this study has been directed toward increasing the strength of the existing harness attachments, which realistically means increasing the strength of the entire personnel "tie-down chain". * The scope of design work and field modification work necessary to increase the strength of the existing 10G personnel restraint system to a 40G system appears to be impractical in some areas of this aircraft for two reasons: (1) the contract specifies that the modification work shall be accomplished by field-level maintenance; (2) the cost of retrofit design components is excessive. Nevertheless, it does appear to be practical to increase the system strength, in the horizontal plane only, to a 30G level for the pilot, copilot, and troop commander, and to a 25G level for the troops. All of these improvements can be accomplished by third- or fourth-echelon field maintenance. None of the modifications will require more than two days downtime with two men accomplishing the work.

Reinforcement of the crew seats and troop seats for vertical loads is not considered, since the amount of work involved is outside the scope of this study; however, the omission of work in this area does not mean that the existing seats are satisfactory. Helicopter crashes involve vertical forces primarily, rather than longitudinal forces (reference 1); therefore, all helicopter crew and passenger seats should be designed with energy absorbers to prevent the vertical forces from exceeding known human limits. The subject of energy-absorbing seats for troops is discussed more fully in reference 7.

The analysis of the crew seats, as shown in the Appendix, is a check only of those components which are obvious potential failure points. A static load test should be conducted to prove that the restraint system is as strong as indicated.

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* The "tie-down chain" includes the lap belt, the shoulder harness, the seat, the floor, and all related anchorages.

Strengthening of the troop commander's seat is considered to be practical, and necessary, due to its unique location, which makes it more feasible to strengthen the seat than to attach the lap belt to basic structure. Unfortunately, no detailed recommendations are made about modifying this seat due to the nonavailability of detailed drawings during the contract period.

Strengthening of the troop seats is not considered in this report because the troop lap belts are attached to the fuselage rather than to the troop seats; consequently, the lap-belt anchorages are analyzed independently of the troop seats. Shoulder straps are not analyzed for the troops because their addition to the existing-design troop seats offers very little gain in personnel crash protection. The existing troop seats should be replaced before shoulder straps are installed (reference 7).

ANALYSIS OF THE CH-47 PERSONNEL RESTRAINT SYSTEMS

The CH-47 (YHC-1) aircraft was evaluated in regard to overall crash safety in January 1960 (reference 3), and a discussion of the personnel restraint systems was included. This analysis is a continuation of the restraint systems evaluation; it includes detailed modifications which will increase the strength of the system.

Reference is made to VERTOL drawing numbers throughout this report to identify structural parts, and reference is also made to contractor and seat vendor drawings; these drawings can be identified as indicated in Table 2.

TABLE 2
DRAWING DESIGNATIONS FOR CH-47 (HC-1B) RESTRAINT SYSTEM

Company or Organization	Description of Item	Drawing Designation
VERTOL Div. of Boeing, Morton, Pa.	Equipment	114E-0000-0
	Structural	114S-0000-0
	Extrusions-VERTOL Std.	VS-00000
Aerosmith Products, Miami, Fla.	Crew Seats - Pilot & Copilot	C-115-00-0
C. R. Daniels, Inc., Daniels, Md.	Troop Cdr. & Troop Seats	A-0000-0
AvCIR, Div. of Flight Safety Foundation, Phoenix, Arizona	Modif. -Restraint Syst.	HC-1-00-0
	Standard Part	AvCIR-00

Since the restraint systems for the cockpit, the troop commander's area, and the troop compartment are entirely different designs, each area is analyzed separately on the following pages.

COCKPIT

General

The crew seats (pilot and copilot) are manufactured by AEROSMITH Products Corp. of Miami, Florida; the seat assembly drawing number is C-115-1. Photographs of the original mock-up seat are shown in Figures 2 and 3. Although these photographs are based on the original mock-up configuration, the overall arrangement is unchanged in the production aircraft.

The seats are constructed primarily from 2024 aluminum alloy and 4130 steel (both possessing good alongation properties). No castings whatsoever are used in the design, which is a very desirable feature from the standpoint of crash safety, as already noted in reference 1. This seat permits horizontal, vertical, and rotational adjustments, as shown in Figure 2.

The combination of horizontal, vertical, and rotational movement in this seat brings the bucket flush to the cockpit floor in the full-down position. The very low adjustment positions attainable with this seat bucket make it feasible for the installation of a 5- to 6-inch-thick energy-absorbing seat cushion. A contoured foam-rubber cushion of 1- to 1.5-inch thickness installed above a 4- to 5-inch-thick energy-absorbing block will definitely enhance the safety of the seat occupant, and the foam-rubber top layer should also make the seat comfortable. The advantages of this type cushion are stated more fully in reference 13. This type of energy-absorbing cushion is already installed in the UH-1A and UH-1B aircraft, and it is used by the Air Force in ejection seats. The installation of this type cushion in the CH-47 crew seats is recommended.

Design and Strength of Existing Harness

The harness components are identified and their strengths recorded as follows:

Lap Belt - Type MD-2, AF Dwg. 54H19650, 3-inch width, 5,000-lb loop strength.
Shoulder Straps - Type MB-2A, AF Dwg. 57D677, 1.7-inch width, 3,600-lb total strength.
Inertia Reels - Type MA-6 (rate of extension), 4,000-lb strength.

The strength of the crew restraint harness components, as listed above, is considered to be adequate (reference 1).

The design configuration of the existing harness is considerably improved if it is modified by the addition of a lap-belt tie-down, which prevents upward belt movement caused by shoulder-harness pull during forward decelerations. This movement can cause abdominal injury due to the impingement of the belt on soft tissue as well as spinal-column injury due to pelvic "submarining" under the belt. The advantages of a lap-belt tie-down are discussed more fully in reference 1.

Strength of Crew Seat and Anchorages

The crew seats are designed to withstand the following loads in accordance with the procurement specification (Report No. PS-399) for the seats.

Direction of Load	Design Load (lb.)	Design Factor*(G)
Forward:		8
Belt	1180	
Shoulder Straps	740	
Sideward (lateral)	1920	8
Downward	1920	8

The loads listed above are design values, and they do not necessarily indicate the maximum strength of the seat. The strength analysis of the seat, in the Appendix, indicates that the seat could withstand about 12G forward at an angle of 26.5 degrees to the longitudinal axis before failure. A preliminary estimate also indicates that the crew seat

* This G factor is based on a 200-pound man and a 40-pound seat.

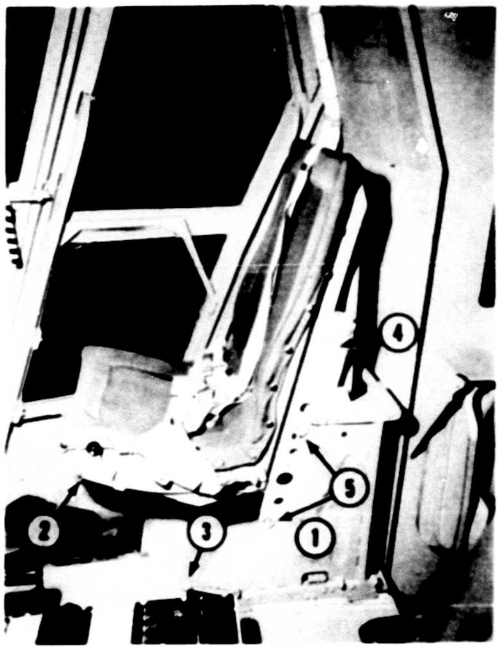


Figure 2. Pilot's Seat Mock-up Configuration.
(1) Seat Base, (2) Inertia Reel Control Handle, (3) Fore/Aft Adjustment Handle, (4) Vertical Movement Track, (5) Rotational Movement Rollers and Track.

Figure 3. Cockpit Side View - Mock-up Configuration.

(as modified by the drawings included in the supplement) will sustain 15 to 20G in a downward direction before failure occurs in the seat bucket. The design strength of the seat in the vertical and lateral directions is greater than that of previous seat designs; however, the design strength is still less than the loads which have occurred in potentially survivable crashes. The seat strength is also incompatible with the lap-belt and shoulder-harness strengths; therefore, the seat should be strengthened in order to provide a "tie-down chain" which approaches the recommended 45G value.

Advantage of Shoulder-Strap Attachment to Basic Structure

Attaching the shoulder strap to the bulkhead at fuselage station 95 will reduce the loads in the seat structure by approximately 20 percent. It is the logical location to consider for reducing longitudinal decelerative loads on the seat floor anchorages.

Disadvantage of Shoulder-Strap Attachment to Basic Structure

A change of seat position in the vertical or longitudinal direction must be preceded by loosening of the shoulder straps if the inertia reel is in the manual-lock position.

Advantages of Lap-Belt Attachment to Basic Structure

The attachment of the lap belts to the cockpit floor would divert a portion of the total decelerative force to the floor. The total longitudinal decelerative force on the seat would be reduced between 40 and 60 percent, dependent upon the frictional forces of the torso on the seat cushion.

Disadvantages of Lap-Belt Attachment to Basic Structure

The 13-inch relative movement of the lap belt to compensate for horizontal, rotational, and vertical seat adjustment would cause a problem with the adjustment buckles (located on either side of the lap belt), since in some seat positions the buckles would be below the seat pan and in other seat positions the buckles would be above the edge of the seat pan. This extreme movement of the 4-inch-wide steel buckle is a serious installation problem, since the belts would necessarily need to be retained by some kind of loop at either side of the seat bucket and the movement of the wide buckles through this loop would probably be highly irritating to the crew member.

Any change in seat position in the forward or upward direction must be preceded by lap-belt loosening. (This is an inconvenience to the pilot; however, the point is of minor importance because a questionnaire, which was mailed to more than 200 pilots, revealed that only 16 percent of helicopter pilots adjust their seats more than once per flight.)

A floor-mounted belt will not hold the occupant as snugly to the seat bucket as a seat-mounted belt, especially in the lateral direction.

Proposed Modifications To Strengthen the Cockpit Restraint System

The advantages of attaching the shoulder-strap inertia reels to basic structure appear to outweigh the disadvantages, and this change is recommended. After several locations up and down the fuselage station 95 bulkhead were considered, it was decided to attach the reels for both crew seats about 5 inches above the cockpit floor. This location relieves the overturning moment on the seat by 17 percent. The moment could be reduced by 38 percent if the reel were located on the bulkhead near the top of the seat back, but this position is not practical because of strap binding on the reel housing as a result of the wide arc through which the strap travels for seat adjustments.

The installation drawing of the inertia reel in a position near the top of the seat back is completed, and it can be used if installation problems occur in the lower position or if a different type of inertia reel is installed which will eliminate the problem of reel-housing rub.

The disadvantages of attaching the lap belts to the cockpit floor appear to outweigh the advantages if it is assumed that the seat structure can be strengthened significantly without removing the lap belts from the seat pan.

An examination of the crew seat and anchorages indicates that the entire system can be increased from its present 10 to 15G design strength to a 25 to 30G strength without the complication of attaching the lap belts to the floor. Although this strength is below the 45G design strength recommended in reference 1, it appears to be the most practical approach to take for this installation.

A total 45G indicated strength can be attained by attaching both the shoulder harness and the lap belt to basic aircraft structure, without any modification to the crew seat itself. However, this solution does not add any strength to the seat and anchorages; this fact is especially

important for lateral loads, because a failure of the seat in the lateral direction can allow the seat occupant to impact against adjacent structure. The functional disadvantages of attaching the lap belt to floor structure have already been noted. Thus, it appears to be more practical to double the longitudinal and lateral strength of the seat rather than to quadruple the longitudinal strength of the harness alone with no increase in seat strength.

The loading direction assumed for the crew seat is based on reference 12, which indicates that aircraft seat designs should sustain loads at 30 degrees to either side of the longitudinal axis; however, the 26.5-degree angle is used, for convenience, to yield an even 50-percent lateral-to-longitudinal load ratio. Although reference 12 is based on fixed-wing aircraft accident statistics, the data are considered to be valid for helicopters until more helicopter accident statistics are collected. A sketch of the assumed loading is shown in Figure 4; this loading is used for the stress analysis given in the Appendix.

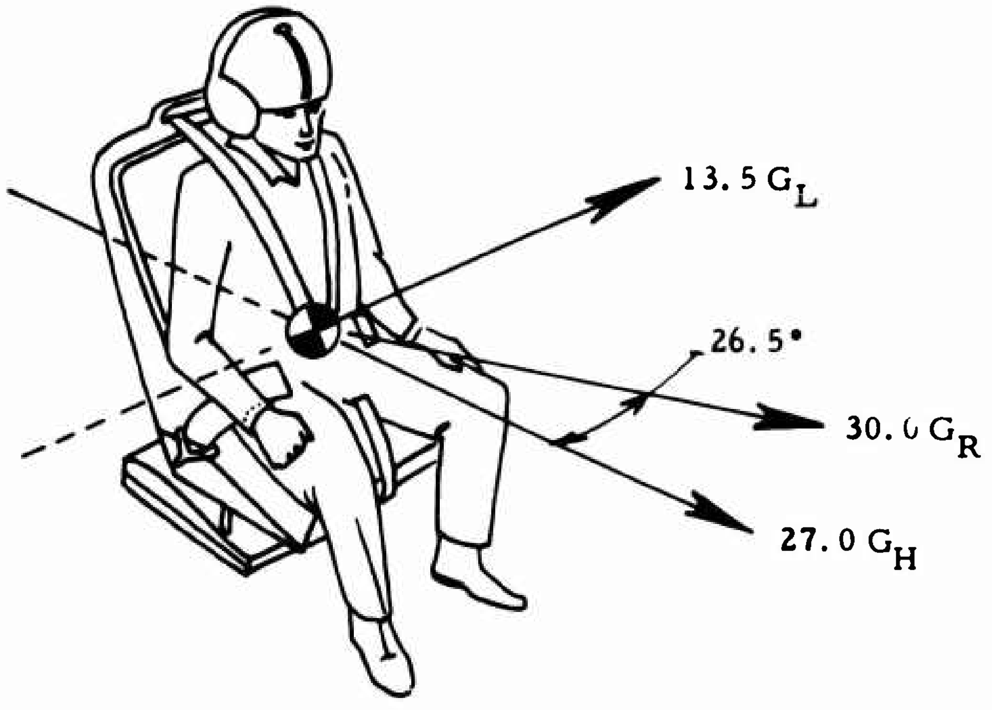


Figure 4. Crew Seat Crash Load Diagram.
Note: If a pure lateral load is applied, the seat can sustain 15-20G. If a pure longitudinal load is applied, the seat can sustain 30-35G.

The modifications proposed to increase the strength of the crew's restraint system to the values shown in Figure 4 are detailed in the supplement to this report (Drawings HC-1-10, -11, -12, -13, -14, -19, -20, -21, and -25). The modifications are simple and can be accomplished by field personnel with retrofit kits. None of the modifications should require grounding of the aircraft for more than two days for any particular modification, if the work is planned in advance and all retrofit parts are in hand.

The modifications proposed for the cockpit area are described briefly below. The drawings referred to are included in the supplement to this report.

1. Lap-Belt Tie-down Strap (HC-1-14). The purpose of the lap-belt tie-down is to prevent the shoulder harness from pulling the belt upward. This function is accomplished by a single tie-down strap (AvCIR-10) attached at the forward edge of the seat pan.

   The lap belt can also be tied down by the use of two side tie-down straps; the straps attach at the belt adjustment buckles at either side of the legs and to the seat pan. This type of installation was shown in the CV-2 Caribou Report (reference 2); it can be used as a guide in making the installation on the CH-47 crew seat if this method of lap-belt tie-down is preferred.

2. Lap-Belt Attachment (HC-1-12). The existing lap-belt attachment is insufficient to sustain the 5000-pound lap-belt design load; therefore, modifications are proposed to increase the strength of the lap-belt attachment to that of the lap belt.

3. Vertical-Track Attachment to Seat Bucket (HC-1-20). The vertical track is attached to the seat bucket by bolts and rivets. The strength of the existing fasteners is insufficient, and it is proposed that additional fasteners be added.

4. Inertia-Reel Attachment to F.S. 95 Bulkhead (HC-1-11). The inertia reel is removed from the back of the crew seat and attached to the bulkhead in order to reduce the overturning moment of the seat.

5. Bucket-Seat Attachments (HC-1-21). The bucket seat is attached to the seat base by a carriage plate with rollers, a

method which allows a rotational and vertical movement of the seat. The rollers on the carriage plate are understrength. It is proposed that the existing rollers be replaced by Electrofilm* coated slides. The dry film lubricant slides, with a coefficient of friction less than .05, should function just as well as the existing rollers since the existing rollers do not have dust covers and will need lubrication periodically.

6. Seat-Base Attachment to Floor Track. The strength of the aft seat leg slider in the floor track is adequate with the exception of the most forward position; it is proposed that this position be blocked off as indicated in drawing HC-1-13 to eliminate its use. The blocking of the forward seat position eliminates 1 inch of forward travel to the seat. This modification has been discussed with engineering personnel at VERTOL and it is not considered to be detrimental to the operation of the aircraft by pilots in the low-percentile category.

7. Floor-Track Attachment to Cockpit Floor (HC-1-13). The existing .19-inch bolts attaching the track to the floor are understrength. It is proposed that additional fasteners be placed between the existing fasteners, and that aluminum collars be added underneath the bolts to provide for local yielding so that the seat slider load can be distributed to adjacent fasteners.

8. Under-Floor Seat-Track Beam Attachment (HC-1-13). The attachment of the under-floor beam to fuselage station 95 bulkhead is understrength, and it is proposed that additional fasteners be installed in this area.

TROOP COMMANDER'S COMPARTMENT

General

The troop commander's seat is located in the entry way between the cockpit and the troop compartment of the helicopter, as shown in Figure 5. The troop commander's seat is manufactured by C. R. Daniels, Inc., of Daniels, Maryland. Although detailed drawings of this seat could not be obtained, it is assumed that it meets strength requirements equal to those of the troop seats.

* Commercial dry-film lubricant.

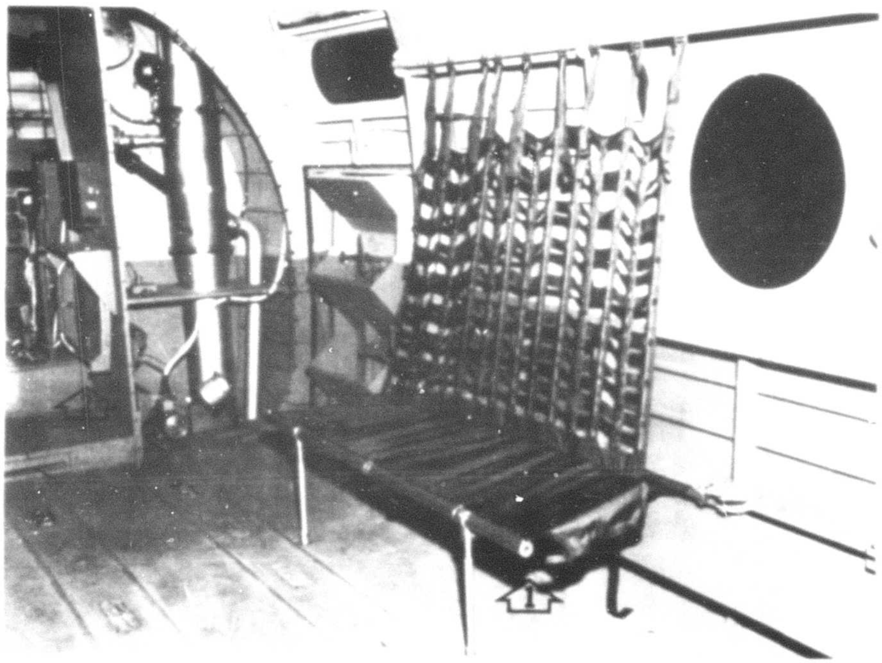


Figure 5. Troop Seat and Troop Commander's Seat.
Arrow 1 shows troop seat installation; arrow 2 shows troop commander's seat.

The strength of the seat has been estimated on the basis of assumptions gleaned from drawing A-6632, "Seat Assembly, Jump-Troop Commander". These estimates indicate that the seat can sustain a 10G load in the vertical direction and that the local attachments of the seat to the aircraft structure are adequate for 40G loads in the horizontal plane; however, during a crash situation, it is highly probable that the seat support at Butt line 8L on the left-hand side could move laterally and thus release the seat as indicated in Figure 6.

The similarly-located rotor support bulkhead of a CH-21 helicopter failed during an experimental crash test conducted recently (reference 4). A similar failure on the CH-47 aircraft would release the troop commander's seat completely. In order to prevent lateral movement of the Butt line 8L bulkhead during a crash, a stud-button arrangement (similar to the troop-seat attachment studs in the cargo compartment) could be installed to insure that the seat would remain with the bulkhead during the deformations occurring in a crash.

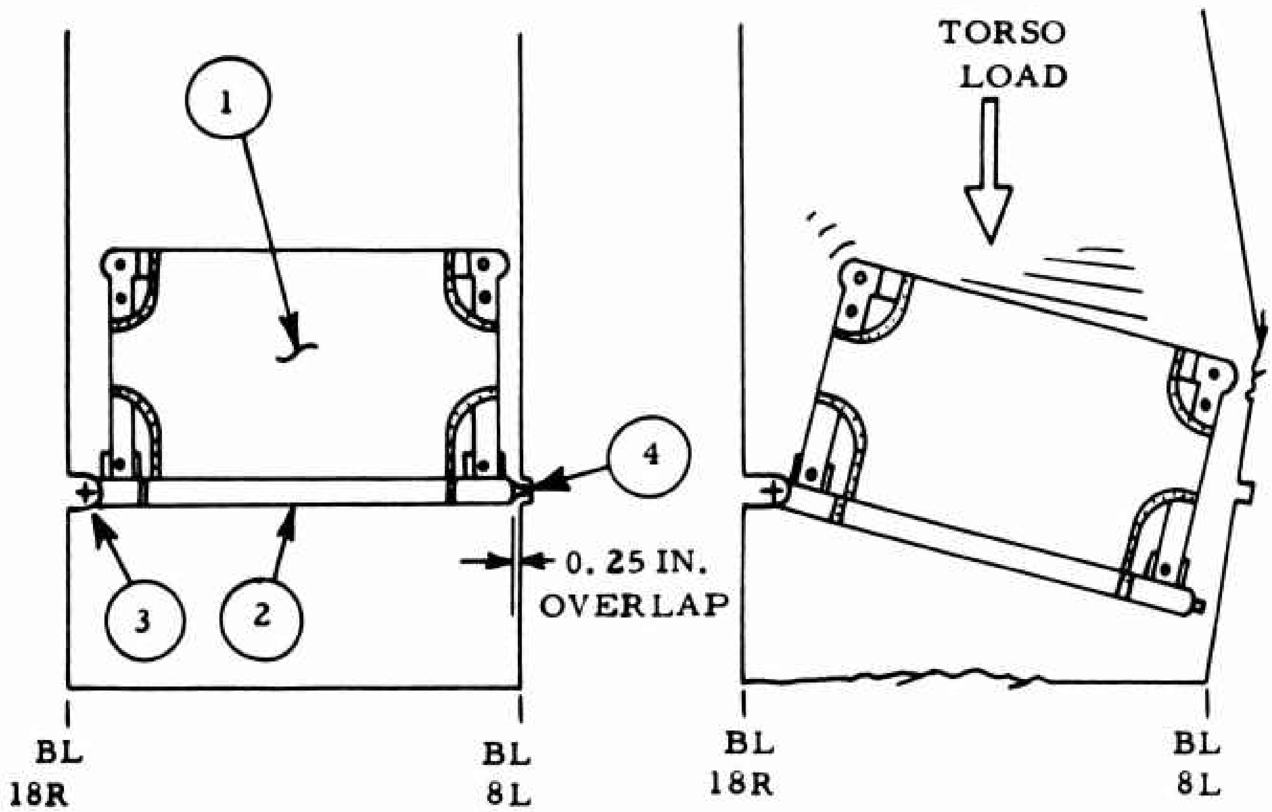


Figure 6. Troop Commander's Seat Attachment - View Looking Aft. (1) Folding Seat Back, (2) Hinged Seat Pan, (3) Hinge Point, and (4) Shear-Pin Engagement.

The 1.5-inch-diameter forward cross tube of the seat should be strengthened by replacing it with a 2024-T3 tube of .125-inch wall thickness or by the insertion of a 1.38-inch O. D. tube of .090-inch wall thickness into the existing cross tube. Strengthening of the cross tube along with an increase of the webbing strength should enable this seat to sustain a 25G vertical load.

Detailed recommendations for the strengthening of this seat are not made, because the necessary drawings were not made available to the contractor during the contract period.

Strength and Applicability of Existing Harness

The existing harness consists of a lap belt only, identified by Federal Stock No. FDC1650-25-25-40-13, which describes a 2-inch-wide belt with a single adjustment buckle. The strength is assumed to be equal to that of the troop belts.

Due to the proximity of the pilot's and copilot's seats in front of the troop commander's seat, the troop commander's head could easily come into contact with these seats during a crash deceleration in which his body "jackknifes" forward over the lap belt (reference 3). The addition of shoulder straps to prevent jackknifing appears to be worthwhile and practical for this installation.

Modifications Proposed To Increase the Strength of the Troop Commander's Restraint System

It has been proposed previously that the forward cross tube of the seat be reinforced and that the shear-pin attachment to the Butt line 8L bulkhead be changed to a button-type attachment. It is also recommended that a shoulder harness and lap-belt tie-down strap be installed as indicated in drawings HC-1-15, -16, -17, -18, -22, -23, and -24.

The shoulder-harness attachments are designed for 4, 000 pounds total load, and the lap-belt tie-down strap is designed for 2, 000 pounds (reference 1). The existing lap-belt attachment bolts are adequate, but the strength of the tubes through which the bolts pass is not known, and it should be checked before this modification is completed. The existing lap belt must be removed and replaced with a military-type belt in order to provide a shoulder-harness attachment point.

The proposed troop commander's restraint system is designed for a load of 40G, but the lap-belt attachments need to be checked to insure that the belt can sustain a 5, 000-pound load.

TROOP COMPARTMENT

General

The troop seats are anchored to the floor and side walls of the fuselage as shown in Figure 5. Although the seats photographed were installed in the CH-47 mock-up, the basic configuration in production aircraft is unchanged. These troop seats are designed to sustain the following decelerations, predicated on a 200-pound occupant:

Seat Bottom	(uniformly distributed)	11G
Seat Back	(uniformly distributed)	3G
Side Load	(concentrated at forward edge of seat pan)	1. 1G

These strength values are too low and the seat design is considered to be inadequate as noted in reference 7.

Strength and Applicability of Existing Harness

The troop seats are provided with lap belts only, as shown in Figure 7. The lap belts are identified by a Federal Stock Number, FDC-1650-27M1. It is assumed that these belts are manufactured in accordance with MIL-B-8607 (as noted in the CH-47 mock-up inspection), which dictates a 5000-pound loop strength.

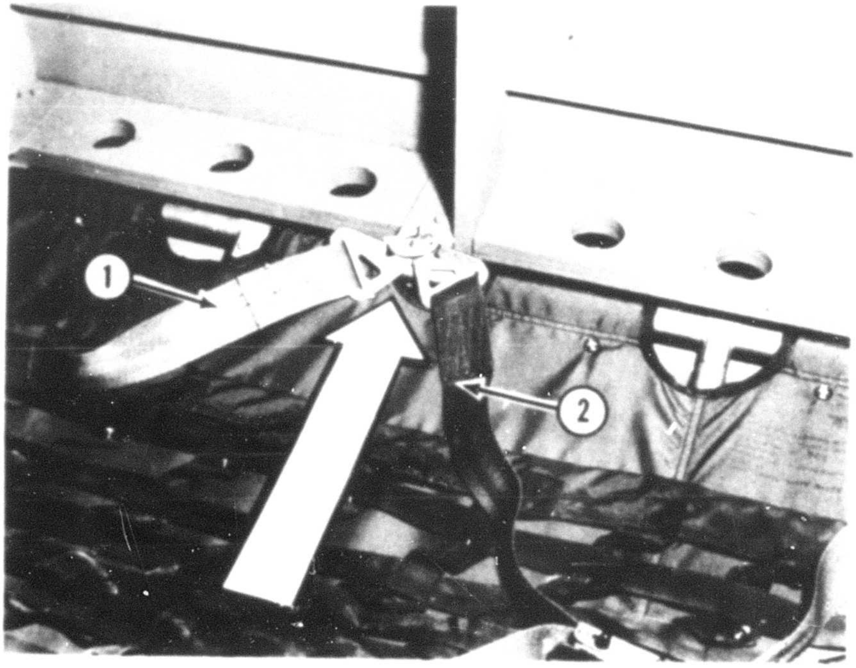


Figure 7. Photograph of Troop-Lap-Belt Mockup. Two occupants are attached to a single tie-down ring, as shown by belts 1 and 2.

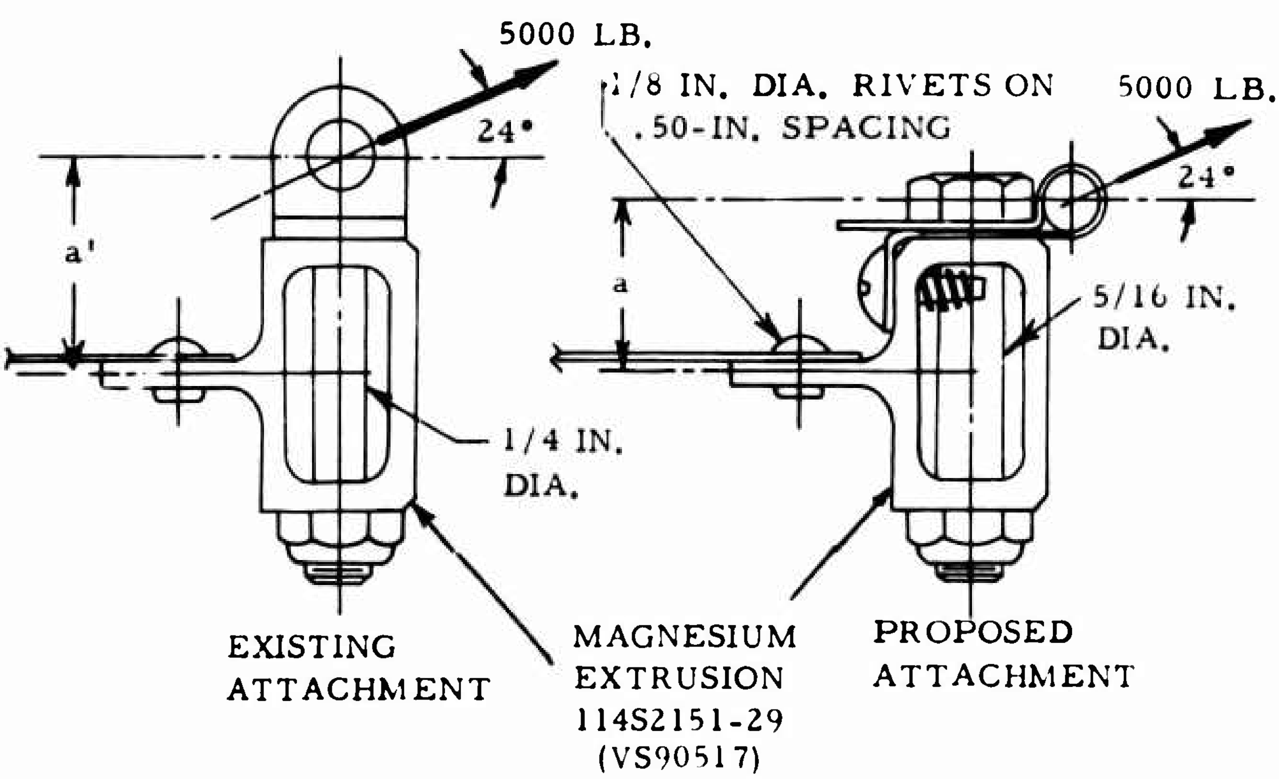
The nylon belt webbing is 1.94 inches wide instead of the desired 3-inch width recommended in reference 1. Although a 3-inch-wide belt is desirable, the desirability must be considered in terms of the additional weight required to effect the change. Apparently, the lowest weight 3-inch-wide belt available is the 2.5-pound, military type MC-1. Since the existing belt weighs only 1.0 pound, a weight increase of 49 pounds (33 troops x 1.5 pounds) would result from the change.

The existing troop lap belts are considered to be acceptable in view of the weight penalty involved in changing to a standard 3-inch-wide military belt, but it is recommended that a new seat belt be designed which is no less than 2.5-inches wide but no greater than 3.0-inches wide. Preliminary calculations indicate that a newly designed lap belt can be achieved which would weigh less than 2 pounds and still fulfill the desired width and strength requirements. The modified type MC-1 lap belt, recommended for the troop commander's seat, is an indication of the weight that can be saved by a newly designed belt, since its weight has been reduced from 2.5 pounds to 2.2 pounds by a redesign of the end fittings alone.

The troop seats are not provided with a shoulder harness, but the addition of a harness is not considered practical unless the troop seats are modified or replaced with a new design. The additional weight and cost of a shoulder strap installation must be weighed against the nebulous benefits to be gained from their use on understrength seats.

Strength of Lap-Belt Anchorages

The lap belts are attached to a magnesium extrusion by means of a ring and eyebolt assembly as shown in the following sketch:



The existing arrangement results in excessive torsional stresses in the extrusion at attachment points adjacent to fuselage frames. In order to reduce the torsional moment, the proposed attachment shown is suggested. This strap and "D" ring arrangement will reduce the torsional moment as well as the bearing stresses of the eyebolt on the magnesium extrusion.

The existing arrangement is also understrength at the attachment of the magnesium extrusion to the intercostal web due to insufficient rivet shear strength. Eight .125-inch-diameter rivets at 346 pounds each are assumed to be effective in resisting the load as noted in the Appendix; hence,

8 rivets x 346 pounds = 2770 pounds.

Thus, it appears that the existing attachment will fail between 2500 and 3000 pounds load or 12 to 15G for a 200-pound occupant.

Modifications Proposed To Increase the Strength of the Troop-Lap-Belt Support Structure

Personnel restrained by lap belts alone can sustain 25G in accordance with the known limits of human tolerance (reference 1); therefore, modifications are proposed to increase the strength of the lap-belt attachments to this value. The strength verification is shown in the latter part of the Appendix, and the detailed drawings (HC-1-30) of the modifications are included in the report supplement.

All of the troop lap belts are attached to a continuous extrusion which extends from the cockpit to the rear cargo loading ramp. The belts are attached to this box extrusion by a ring and eyebolt assembly located on 20- and 24-inch spacings. Two belt ends are attached to each ring as shown in Figure 7. The strength of the .25-inch-diameter eyebolt is inadequate, and the eyebolt also applies excessive torque to the box section. The proposed modification to alleviate the torque in the box section is the deletion of the existing eyebolts (ACA-2128) and replacement with formed straps (HC-1-30). The formed straps apply the load nearer the shear center of the box section, thereby reducing the shear stresses to an acceptable level.

At some attachment points along the box section, it is not feasible to attach the formed strap; thus, two other methods are used at these locations. The first method makes use of a .31-inch-diameter eyebolt which was made particularly for this purpose on the CV-2 Caribou aircraft.

The other method extends the formed strap from the box section outboard to the outer skin-stiffener combination.

Although it is desirable to make the modifications exactly alike for all attachment points, this is very difficult to accomplish with retrofit-type modifications. Even though the proposed modifications include three different attachment fittings, the installation appears to be justifiable on the basis that the strength of the attachments is doubled with only a 1-pound weight increase.

SUMMARY OF COST AND WEIGHT MODIFICATIONS, ASSUMPTIONS USED FOR WEIGHT AND COST ESTIMATES

The cost of the modifications is based on the cost of the retrofit kits alone. The cost of man-hours required to install the kits is not computed, because it is anticipated that man-hour estimates will be made by the U. S. Army Aviation and Surface Materiel Command.

Reference 10 is used as a guide in estimating manufacturing times in producing the retrofit kits. Some of the estimates are based on inquiries at local machine shops in the Phoenix area. Some basic assumptions used in the cost estimates are listed below:

For Single Prototype Kits

1. Only standard tools and machines are used.
2. No jigs or fixtures of special design are used.

For Multiple-Run Kits

1. Raw materials are premarked.
2. More sophisticated machines such as multiple-spindle drills are used.
3. Positive stops are provided on all machines for pilot alignment.
4. Special jigs and fixtures are designed as needed.
5. A learning curve of 90 percent is used in long, repetitive runs.

A cost and weight summary is presented in Table 2.

TABLE 2
COST AND WEIGHT SUMMARY OF PROPOSED MODIFICATIONS

Dwg. No.	Title	Weight per A/C*(lb)	Cost of Parts per A/C in Dollars 1 A/C	10 A/C	50 A/C
Cockpit & Troop Commanders Area					
HC-1-11	Install.-Inertia Reel L&R Side	0.12	10.00	5.00	3.00
HC-1-12	Reinf. Lap-Belt Attachment	Zero	10.00	3.70	3.00
HC-1-13	Reinf.-Cockpit Floor	1.01	20.00	13.00	10.00
HC-1-14	Tiedown Strap-Lap Belt	0.55	5.25	3.11	2.34
HC-1-16	Install.-Attach. Ftgs. Troop Cdr.	0.21	30.00	18.00	14.00
HC-1-19	Install.-Control Cable & Shoulder Harness	0.12	80.02	79.52	24.80
HC-1-20	Reinf.-Vert. Track-Seat Bucket	negligible	none	none	none
HC-1-21	Modification-Carriage Assembly	1.40	63.00	44.00	40.00
HC-1-24	Install.-Restraint System-Troop Cdr.	2.74	82.00	58.00	32.00
HC-1-25	Reinf. Lock Pin-Seat Base	.29	6.00	5.00	3.00
	Cost of Jigs & Fixtures	---	------	15.00	6.00
	Sub-Total	6.44	306.27	244.33	138.14
Troop Compartment					
HC-1-30	Modification-Lap Belt Attach. Troop 5000 lb	1.18	192.50	175.00	160.00
	Cost of Jigs & Fix.	---	------	10.00	4.00
	Sub-Total	1.18	192.50	185.00	164.00
Total for Complete Aircraft		7.62	498.77	429.33	302.14

* These weights are total installed weights including fasteners.

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APPENDIX

STRENGTH ANALYSIS OF CH-47 AIRCRAFT PERSONNEL RESTRAINT SYSTEMS

GENERAL CONDITIONS

Use is made of "limit analysis" concepts (reference 5 and 6). Under crash conditions, large deflections and plastic strains are considered to be acceptable provided the strains are well below the maximum elongation of the material and the structural integrity of the seat and anchorages is maintained.

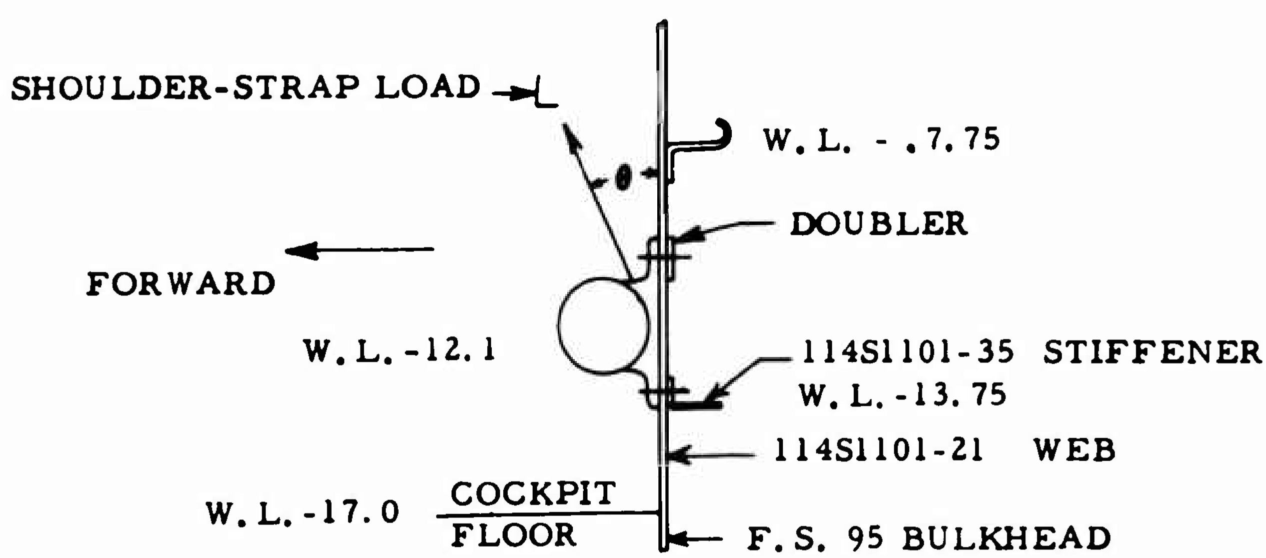
Unless otherwise indicated, specific strength criteria are taken from MIL-HDBK-5, March 1961.

Human dimensions are obtained from Anthropometry of Flying Personnel - 1950 (reference 9), for the purpose of calculating the restraint harness loads.

CREW SEATS

Inertia Reel Attachment

Consider first the left-hand installation as shown on drawing HC-1-11. The inertia reel is installed on fuselage station 95 bulkhead, centered at Butt line 21.0 L and W.L. -12.1 as shown below:



The shoulder-strap load is inclined from the vertical at an angle, θ, which varies from 0^o to 30^o (nominally).

The most severe shear load upon the attachment would occur for the load angle θ equal to zero degrees. The total shear would then equal L, for which a design value equal to the inertia-reel strength of 4000 pounds is assumed.

The shear capacity of the four AN 3 bolts would be governed by the bearing strength of 7075-T6 (.032) bulkhead web. The area in bearing is

$$A_{br} = 4\,(.19)\,(.032) = .0243 \text{ sq in.};$$

and for an ultimate bearing stress of 133 ksi,

$$F_1 = (133{,}000)\,(.0243) = 3230 \text{ lb.}$$

Additional strength is obtained by the three .125-inch-diameter rivets through the HC-1-11-1 doubler and three rivets in the 114S1101-35 stiffener.

The shearing strength of the six rivets (at 374 lb) is

$$F_2 = 6\,(374) = 2240 \text{ lb.}$$

The total shear strength of the connection is then

$$F_1 + F_2 = 3230 + 2240 = 5470 \text{ lb}$$

and

$$\text{M.S.} = \frac{5470}{4000} - 1 = \underline{.37}$$

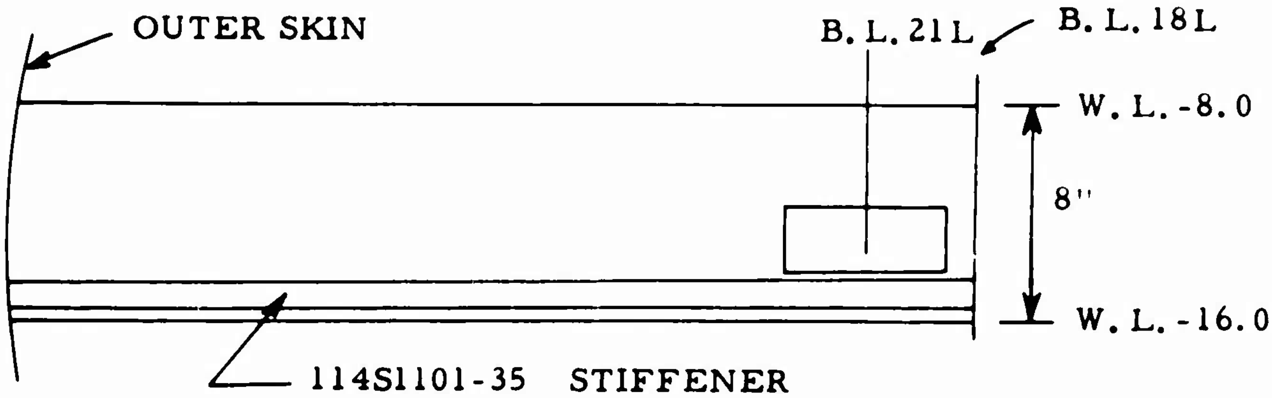
The most severe load component normal to the bulkhead occurs when the angle θ is 30 degrees, and the normal load is

$$4000 \sin 30^o, \text{ or } 2000 \text{ lb.}$$

A small deflection elastic analysis would lead to excessive theoretical bending stresses in the lateral stiffeners. Actually, local yielding would take place, "plastic hinges" forming in the stiffeners, and a new equilibrium configuration would result. For the resulting large

deflection (normal to the bulkhead), the normal load component would be sustained by membrane "strap" action rather than beam-bending resistance.

An assumed effective lateral strap is as shown below:

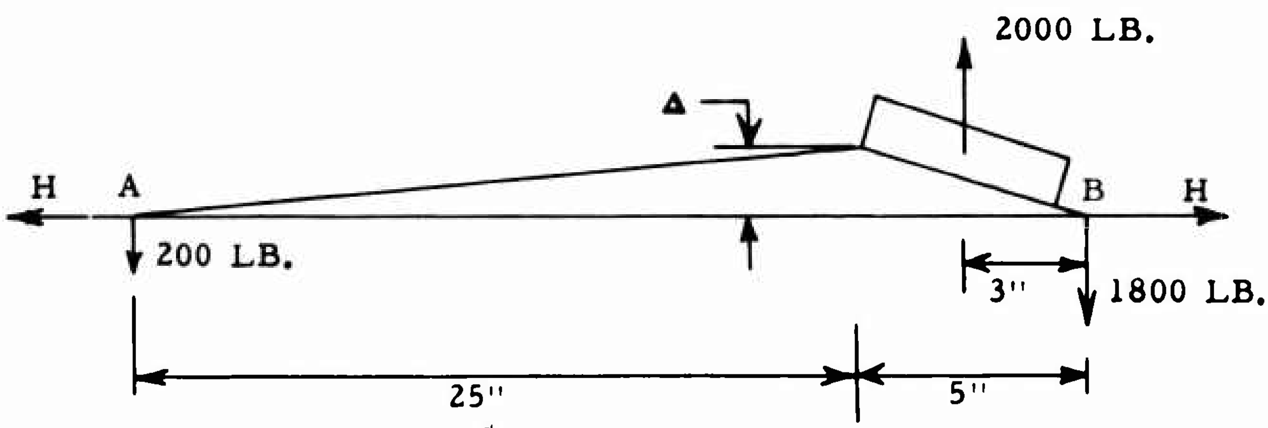


Effective Strap Area

Cross-sectional area of effective strap:

web area = 8 x .032	=	.256 sq in.
stiffener area	=	.080 sq in.
Total	=	.336 sq in.

Assuming that the reel and attachment act as a rigid insert in the lateral strap, the action would be as illustrated below:



For membrane tension in the strap at the left end,

$$200 = \frac{\Delta H}{25} \qquad \text{or} \qquad H = \frac{(25)(200)}{\Delta} = \frac{5000}{\Delta}$$

As the points A and B are held essentially fixed, due to the rigidity of the structure at each end, the lateral strain may be determined from geometric considerations.

$$\epsilon = \frac{\text{change in length}}{\text{original length}}$$

$$\epsilon = \frac{\sqrt{25^2 + \Delta^2} + \sqrt{5^2 + \Delta^2} - 30}{30}$$

For small Δ compared with length,

$$\epsilon = \frac{1}{2}\left(\frac{\Delta^2}{25}\right)\frac{25}{30} + \frac{1}{2}\left(\frac{\Delta^2}{5}\right)\frac{5}{30} = \frac{\Delta^2}{250}$$

The lateral load H, expressed in terms of strain using Hooke's law, is

$$H = E A \epsilon;$$

or solving for strain,

$$\epsilon = \frac{H}{EA} = \frac{5000}{EA\Delta}$$

Equating the two expressions for strain,

$$\frac{\Delta^2}{250} = \frac{5000}{EA\Delta} = \frac{5000}{(10^7)(.336)\Delta}$$

or

$$\Delta^3 = \frac{(5000)(250)}{10^7(.336)} = .372 \qquad \Delta = .72 \text{ in.}$$

Thus, $$H = \frac{5000}{\Delta} = \frac{5000}{.72} = 6950 \text{ lb.}$$

Assume the rivet pattern at B. L. 18.0 from W. L. -17.0 up to W. L. -7.5 is effective in sustaining this load. Consequently, fourteen .156-inch-diameter rivets (at 570 pounds in shear) would accept the shear load and the total shear capacity is

$$F = (14)(570) = 8000 \text{ lb}$$

or

$$M.S. = \frac{8000}{6950} - 1 = .15.$$

Some assistance may be assumed from vertical membrane stretching of the web, which provides a still larger margin of safety. The load component at B. L. 18. 0 in the forward direction (1800 pounds) would be carried by two added AN3 bolts as shown in drawing HC-1-11.

The right-hand installation could be analyzed in the same manner; however, due to elastic compliance of the vertical stiffener at B. L. 18, the end points of the effective strap would not be considered fixed. This would serve to reduce the strap load by favorable end movement, resulting in a margin of safety greater than for the left-hand installation.

Lap-Belt Attachment

A design load of 3800 pounds for the lap-belt attachment is assumed in accordance with reference 8. This load is based on a 5000-pound belt capacity with an unequal load distribution (due to lateral loads) of 3 to 1, which yields a 3800-pound load on one attachment and a 1200-pound load on the other.

The AN4 attachment bolt in double shear provides a high margin of safety. The attachment clevis strap (C-115-3-115) has insufficient crushing strength without additional heat treatment; therefore, it is recommended that this part be heat treated to 180 ksi tensile strength. The strap area in bearing is

$$A_{br} = (2)(.25)(.032) = .016 \text{ sq in.}$$

Hence, for 180-ksi heat treatment, $F_{br} = 250$ ksi (for $\frac{e}{d} = 1.5$)

and

$$F = (.016)\, F_{br} = 4000 \text{ lb}$$

$$M.S. = \frac{4000}{3800} - 1 = \underline{.05.}$$

The pivot pin (C-115-3-117) is welded to the clevis strap; therefore, it, too, would be heat treated to 180 ksi. The double shear strength of this pin in the heat-treated condition provides a high margin of safety.

It is, furthermore, recommended that the attachment bracket (C-115-3-77) also be heat treated to 180 ksi. This would provide a high margin of safety for the bearing strength at the three tie-down bolts.

In view of uncertainties in the behavior of the phenolic block (which holds the attachment away from the bucket side panel), it is recommended that the existing AN509-10 tie-down bolts be replaced by .19 lockbolts or NAS 333 (high-strength) bolts. These bolts would provide for the combined bending and shear that would occur with a partial failure of the phenolic block.

The bearing area in the (.060) 2024-T4 side panel of the seat bucket for the three tie-down bolts is

$$A_{br} = (3)(.19)(.060) = .0342 \text{ sq in.}$$

The load capacity is then

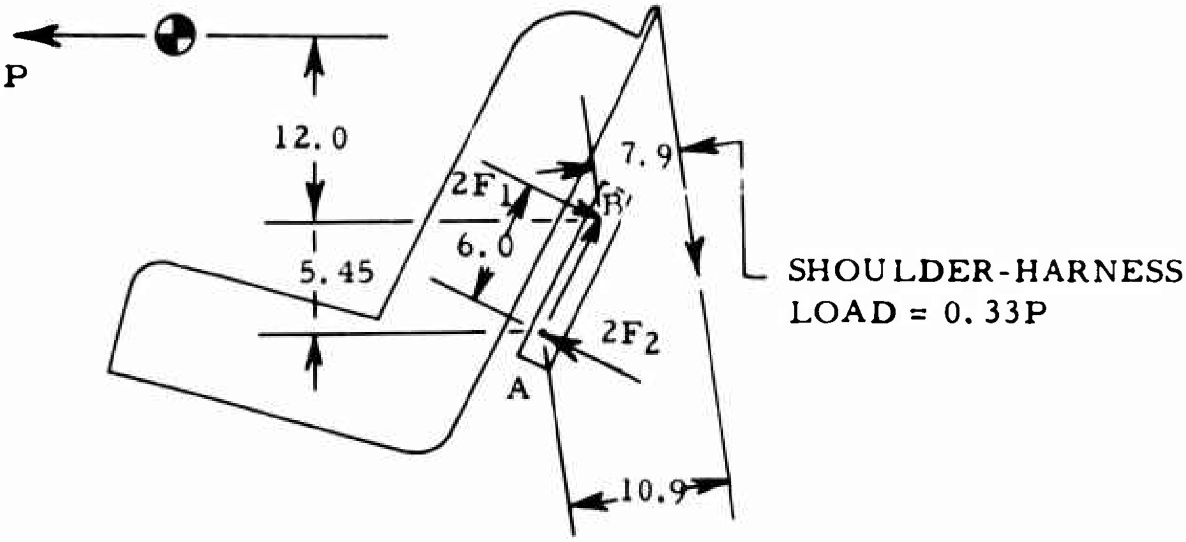
$$F = A_{br} F_{br} = (.0342)(100{,}000) = 3{,}420 \text{ lb}$$

$$\text{M.S.} = \frac{3420}{3800} - 1 = \underline{-.10.}$$

However, there would be benefit from friction due to bolt tension and the presence of a backup plate. The actual margin of safety would be greater than indicated.

Bucket-Seat Attachments

Consider a free-body diagram of the seat bucket and occupant in the full-up and full-clockwise rotation position, which is the critical position for seat-bucket reactions, under a purely longitudinal load P. It is assumed that the shoulder-harness load is one-third of the applied load in accordance with experimental data as noted in reference 1.

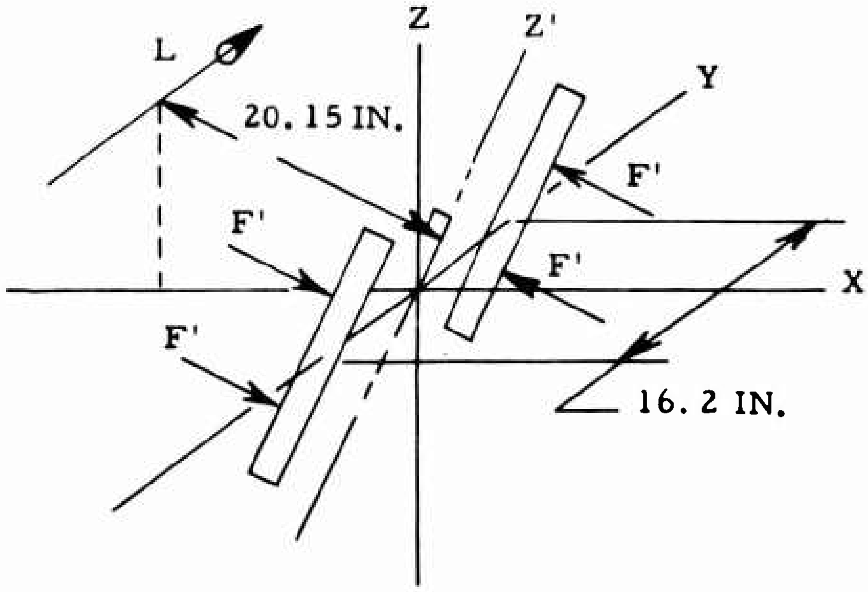


Equating moments about point A and about point B independently to zero, the reactions F_1 and F_2 are found to be

$$F_1 = 1.155\ P$$

$$F_2 = .784\ P$$

The same free body under a purely lateral load is as indicated below:



Considering moments about the Z' axis, F' is evaluated to be

$$F' = .622\ L;$$

or assuming a load angle of 26.5 degrees with the longitudinal axis, L is $\frac{1}{2}$ P and

$$F' = .311\ P.$$

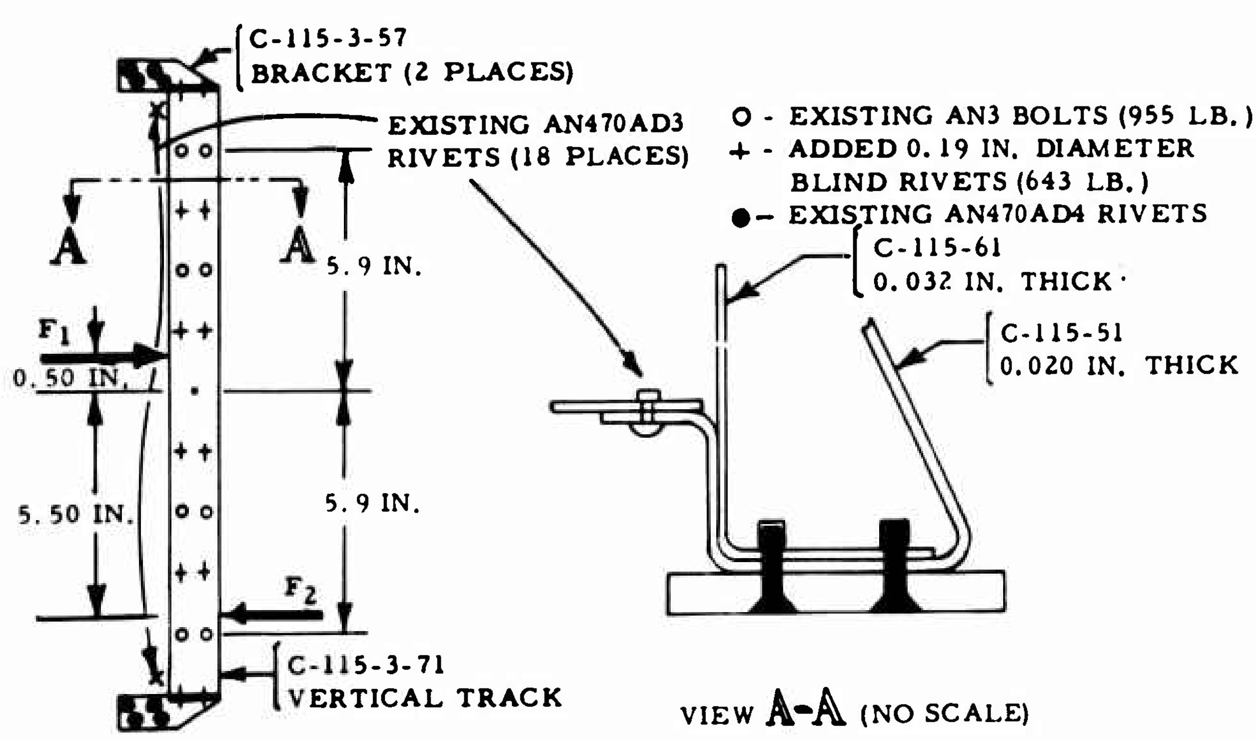
Superimposing the lateral upon the longitudinal loading, the resulting reaction forces are either of two combinations since the lateral load may be in either direction.

$$\left.\begin{array}{l} F_1 = 1.47\ P \\ F_2 = .47\ P \end{array}\right\} \text{ or } \left\{\begin{array}{l} F_1 = .84\ P \\ F_2 = 1.10\ P \end{array}\right.$$

For a 200-pound occupant and seat bucket undergoing a deceleration of 30G, P is 5370 pounds; hence,

$$\left.\begin{array}{l} F_1 = 7890\ \text{lb} \\ F_2 = 2520\ \text{lb} \end{array}\right\} \text{ or } \left\{\begin{array}{l} 4510\ \text{lb} \\ 5900\ \text{lb} \end{array}\right.$$

These forces are applied to the vertical track by rollers on the carriage assembly. For the full-up position, the forces are located as shown below:



Replacing F_1 and F_2 by an equivalent force and couple at the track center C, we have

$$M_c = F_1 \ (.5) + F_2 \ (5.5)$$

$$F_x = F_1 - F_2$$

thus,

$$\left.\begin{aligned} M_c &= 17,780 \text{ in.-lb} \\ F_x &= 5370 \text{ lb} \end{aligned}\right\} \text{or} \quad \left\{\begin{aligned} &34,750 \text{ in.-lb} \\ &-1,390 \text{ lb} \end{aligned}\right\}$$

The strength of the AN3 bolts is governed by the crushing strength of the 2024-T3 sheets of .052-inch total thickness (reference Aerosmith Dwg. C-115-3), which is 955 pounds per bolt, a value which is insufficient to resist the applied loads.

It is proposed that eight MS20601 (.19-inch-diameter) blind rivets be added as shown in the foregoing sketch. Employing the "lower bound" limit analysis theorem, which states that the load associated with a statically admissible stress distribution forms a lower bound to limit (or capacity) load, we consider two such distributions, one for each combination of resultant force and couple given above.

First, let two AN3 bolts at each extremity resist the applied couple (17,780 in.-lb). Thus, the maximum moment capacity is

$$M_c = (2)\ (955)\ (11.8) = 22,500 \text{ in.-lb}$$

and

$$\text{M.S.} = \frac{22,500}{17,780} - 1 = \underline{.27.}$$

Associated with this, let the remaining fasteners support the resultant applied force (5370 lb). Then

$$F_x = 4 \text{ bolts } (955) + 8 \text{ rivets } (643) = 8960 \text{ lb}$$

and

$$\text{M.S.} = \frac{8960}{5370} - 1 = \underline{.67.}$$

Second, let all the fasteners except the four central .19-inch-diameter blind rivets resist the applied couple of 34,750 in.-lb for the other combination. Thus, the moment capacity is

$$M_c = (2)(955)(11.8) + (2)(643)(8.5) + (2)(955)(4.2)$$

$$= 41,490 \text{ in.-lb}$$

and

$$\text{M.S.} = \frac{41,490}{34,750} - 1 = \underline{.19.}$$

The resultant force (1390 lb) associated with the above moment can be sustained by the four centrally located .19-inch-diameter blind rivets. Thus,

$$F_x = (4)(643) = 2570 \text{ lb}$$

and

$$\text{M.S.} = \frac{2570}{1390} - 1 = \underline{.85.}$$

The resultant force and couple are transmitted from the vertical track (C-115-3-71) to the seat bucket by means of a vertical row of .094-inch-diameter rivets along the forward edge and by riveted track support brackets (C-115-3-57) at the top and bottom of the track support as indicated in the previous sketch. As the existing connection strength is insufficient to transmit the applied loads, it is recommended that .125-inch-diameter MS-20600 blind rivets (186 lb each shear) be added between existing rivets in the vertical rivet row along the forward edge of the track support. For a .75-inch pitch of existing rivets (.094-inch-diameter at 192 lb), the new shear capacity at .375-inch pitch is

$$(186 + 192)\left(\frac{1 \text{ inch}}{.75 \text{ inch}}\right) = 500 \text{ lb per inch.}$$

Assuming that the lower bracket can sustain load by direct bearing against the seat back, a statically admissible stress distribution for the first force and couple may be as follows: Let the lower 12 inches of the vertical rivet row resist the force F_x (5370 lb); the total capacity is

$$F_x = (12)(500) = 6000 \text{ lb}$$

and

$$M.S. = \frac{6000}{5370} - 1 = \underline{.12.}$$

Then, the remaining 1-inch of rivets at the top of the track, plus the upper brackets, together with the lower bracket in direct bearing would resist the applied couple (17,780 in-lb). The upper bracket strength is governed by crushing of the four .125-inch-diameter rivets in the .020-inch sheet; thus, at 250 pounds each, the capacity is 1000 pounds. The total moment capacity is then 1000 pounds from the bracket plus 500 pounds from the last inch of rivets at a lever arm of 13 inches, or

$$M_c = (1000 + 500)(13) = 19,500 \text{ in.-lb}$$

and

$$M.S. = \frac{19,500}{17,780} - 1 = \underline{.10.}$$

To resist the other force-couple combination, assume that the lower 3 inches of the vertical rivet row acts to resist the force (1390 lb). Then

$$F_x = (3)(500) = 1500 \text{ lb}$$

and

$$M.S. = \frac{1500}{1390} - 1 = \underline{.08.}$$

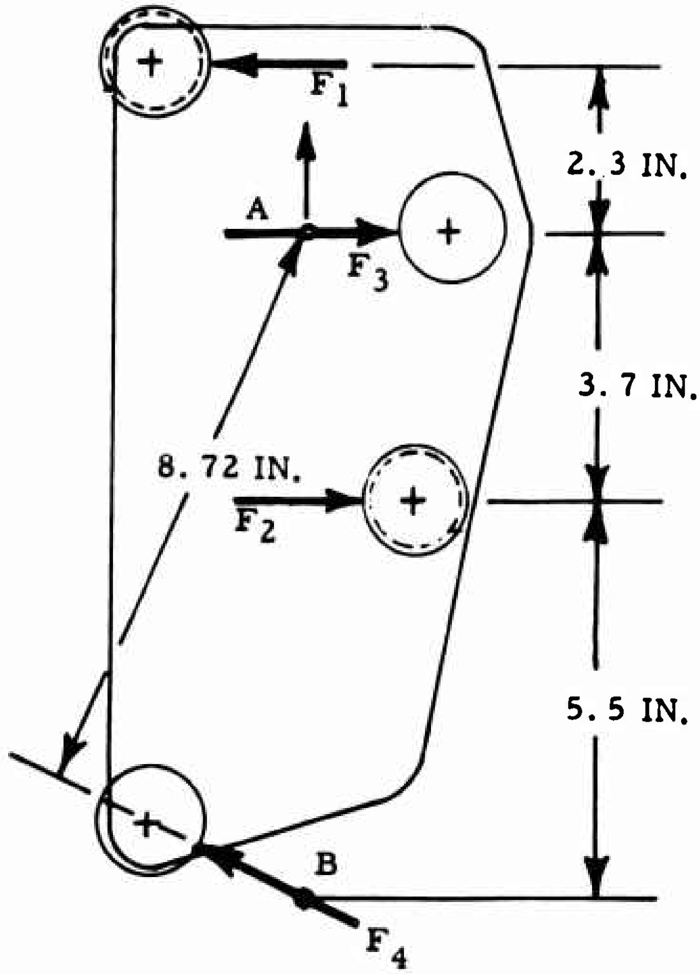
The remaining rivet row, that is, the upper 10 inches, which corresponds to a 5000-pound capacity, is then assumed to sustain a portion of the applied couple (34,750 in.-lb). The lever arm for this force is 8 inches. Also, the upper bracket, with a 1000-pound shear capacity, acts at a lever arm of 13 inches. Then

$$M_c = (5000)(8) + (1000)(13) = 53,000 \text{ in.-lb}$$

and

$$M.S. = \frac{53,000}{34,750} - 1 = \underline{.53.}$$

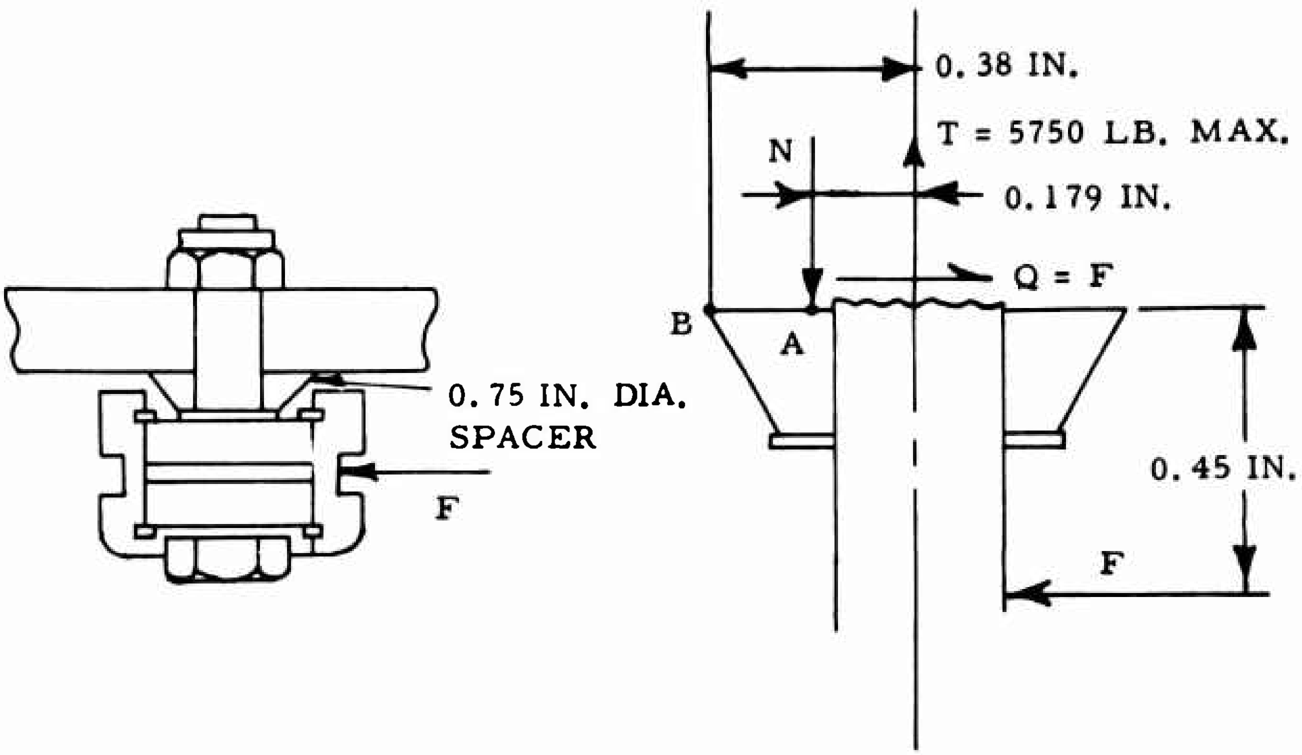
Consider next the carriage assembly (C-115-5) with forces F_1 and F_2 applied by the seat bucket vertical track. Forces F_1 and F_2 are resisted by F_3 and F_4 from the curved track of the seat base (reference C-115-6). Forces F_3 and F_4 act perpendicular to the curved track as indicated by the free-body sketch. This force diagram also assumes that the seat bucket is in the full-up position and that the carriage is in the full-clockwise (down) position as stated previously.



Considering moments about points A and B respectively, the forces F_3 and F_4 are calculated to be either of two combinations (depending upon lateral force direction):

$$\left.\begin{aligned} F_3 &= 8320 \text{ lb} \\ F_4 &= 3150 \text{ lb} \end{aligned}\right\} \quad \text{or} \quad \left.\begin{aligned} &2110 \text{ lb} \\ &3690 \text{ lb} \end{aligned}\right\}$$

To evaluate the load-carrying capacity of the existing rollers (on the carriage assembly), a statically admissible stress distribution is first assumed as illustrated.



The location of N is based upon a uniform compression over a semi-circular area of contact on the spacer. For an AN-5 bolt, the ultimate tension is 57[illegible] pounds. Hence, from moments about point A,

$$F = 2280 \text{ lb},$$

which represents a lower bound for the limit load.

Assuming as a kinematically admissible displacement pattern, a rotation about the edge of the spacer (point B), an upper bound to the limit load may be computed (upper bound theorem), which is

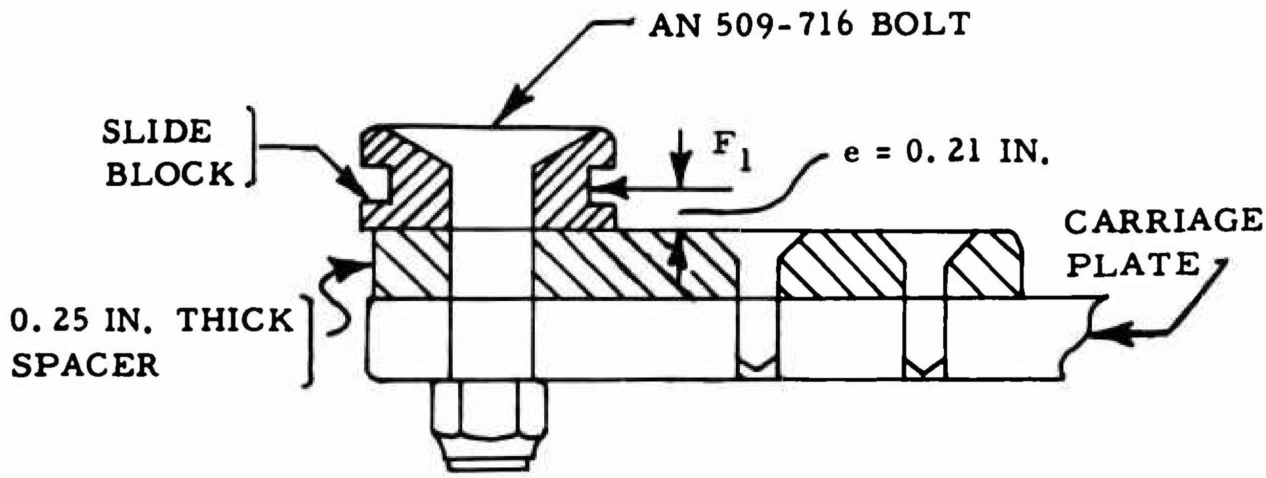
$$F = 4800 \text{ lb}.$$

Using the average as a plausible ultimate load on the roller, we obtain

$$F_{ult} = 3540 \text{ lb}.$$

Since the maximum roller load corresponding to a deceleration of 30G at 26.5° to the longitudinal axis has been shown above to be 8320 lb, the roller capacity would limit the G load to approximately 13G for the most critical seat position.

Four slide block assemblies to replace existing rollers, as shown in drawing HC-1-21, are recommended to increase the seat crashworthiness. Shown below is a typical guide block assembly (for the F_1 force).



The spacer block is attached to the carriage plate with three .19-inch-diameter thread-forming screws which integrate the plate and spacer into a beam which can resist the loc·ˡ ˀ·nding.

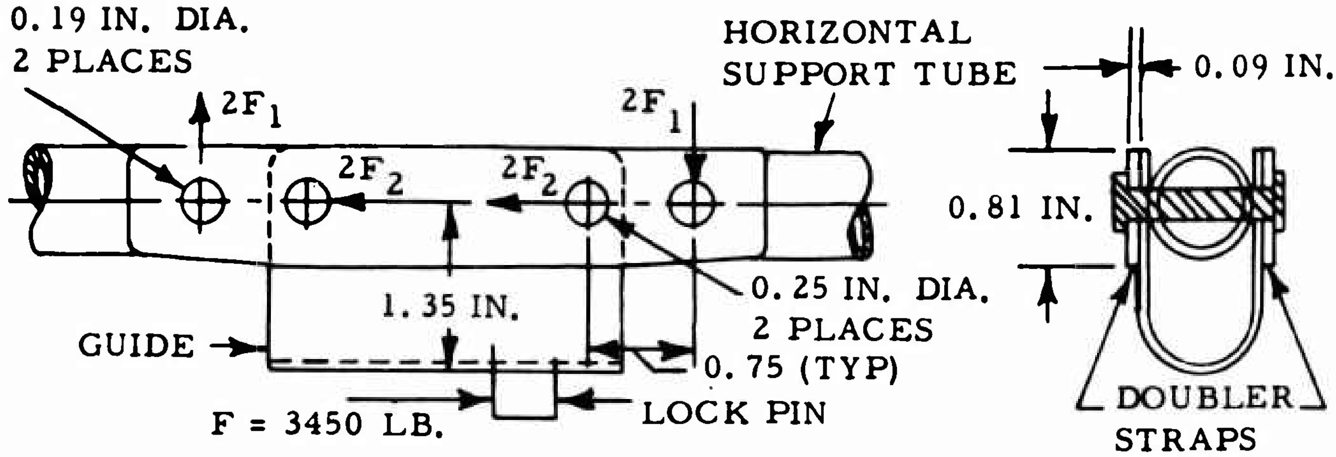
As the eccentricity, e, is small, the ultimate load, F, is governed by the shear strength at section A of the AN509 bolt. Using ultimate shear strengths,

$$M.S. = \frac{11,250}{7,890} - 1 = \underline{.43.}$$

Correspondingly high margins of safety exist at the other modified roller attachments.

Lock-Pin-Assembly Attachment (C-115-6-101)

The lock-pin guide assembly is attached to the horizontal support tube by two .19-inch-diameter bolts. For a 30G longitudinal deceleration and a 230-pound occupant and seat combination, the shear force per lock pin (F) is 3450 pounds. The existing .19-inch-diameter bolts are insufficient for the resulting force and couple to be transmitted to the .75-inch-O.D. support tube. It is proposed that doubler straps be added along with two .25-inch-diameter bolts (replacing the existing bolts) and two .19-inch-diameter bolts as shown in the following sketch.



Assume that the couple is transmitted through the extreme bolts. Then,

$$(2\ F_1)\ (3.5) = (3450)\ (1.35)$$

or

F_1 = 665 pounds per shear surface.

F_{bru} = 825 lb for a .19-inch-diameter bolt in the .049-inch tube; thus,

$$\text{M.S.} = \frac{825}{665} - 1 = \underline{.24.}$$

The shear force (F) is assumed to be reacted by the .25-inch-diameter bolts; hence,

$4\ F_2 = 3450$ or $F_2 = 860$ lb.

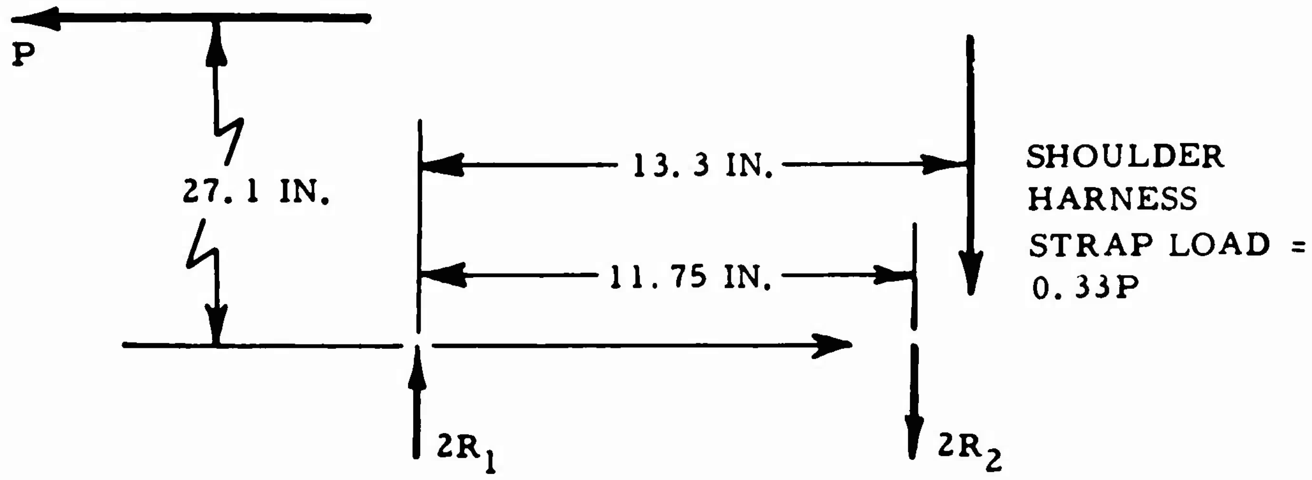
F_{bru} = 1100 lb for .25-inch-diameter bolt in the .049-inch tube; thus,

$$\text{M.S.} = \frac{1100}{860} - 1 = \underline{.28.}$$

Attachment of Seat Base to Floor

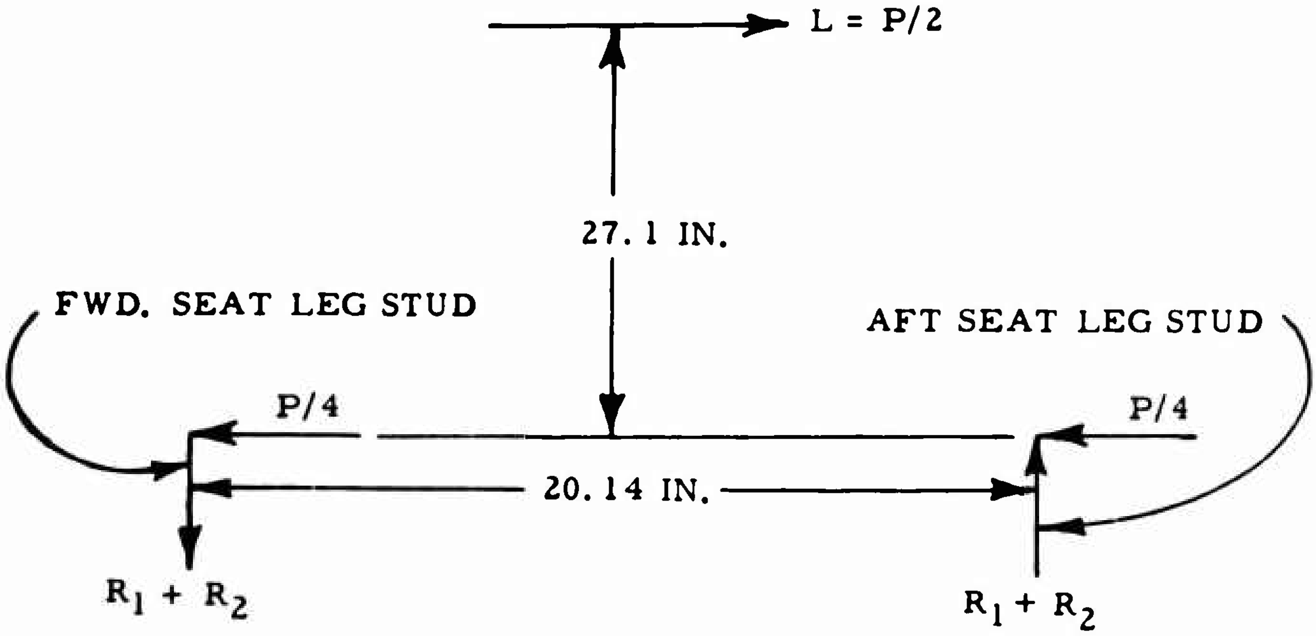
Consider the entire seat and occupant as a free body with the seat in full-up position and full-counterclockwise rotation, which is the critical position for this analysis.

For a longitudinal load (P) only, the seat leg reactions are illustrated as follows:



For equilibrium, $R_1 = 1.13P$ $R_2 = .965P$.

For a lateral load (L) only,



Assuming $R_1 = R_2$, from equilibrium

$$R_2 = .672\ L = .336\ P$$

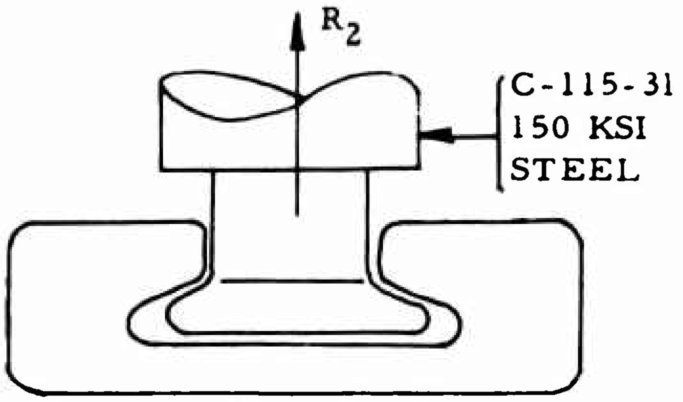
Combing the longitudinal and lateral loads, the maximum reaction R_2 is

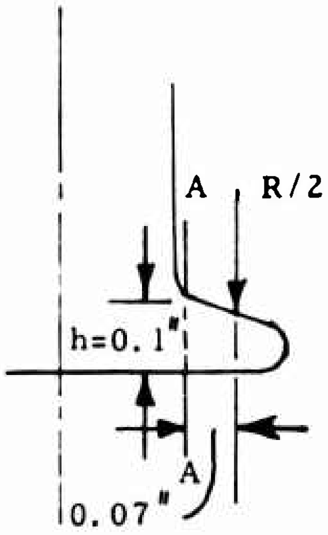
$$R_2 = 1.30\ P, \text{ and maximum } R = 1.47\ P.$$

Assuming 220 pounds as the weight of the occupant and seat* and a 30G deceleration,

$$R_2 = 30G \times 220 \text{ lb} \times 1.3 = 8580 \text{ lb.}$$

Consider first the load on the rear track stud (C-115-6-31):





The plastic moment at section AA is computed (for $T_{ty} = 140$ ksi.).

Since the stud is 1 inch long,

$$M_p = F_{ty} \times \frac{\text{width of section x (depth)}^2}{4} =$$

$$140,000 \frac{(1)\ (0.1)^2}{4} = 350 \text{ in.-lb}$$

$$\frac{R}{2}\ (.07) = 350 \qquad \text{or} \qquad R = 10,000 \text{ lb.}$$

Hence, for a 30G load,

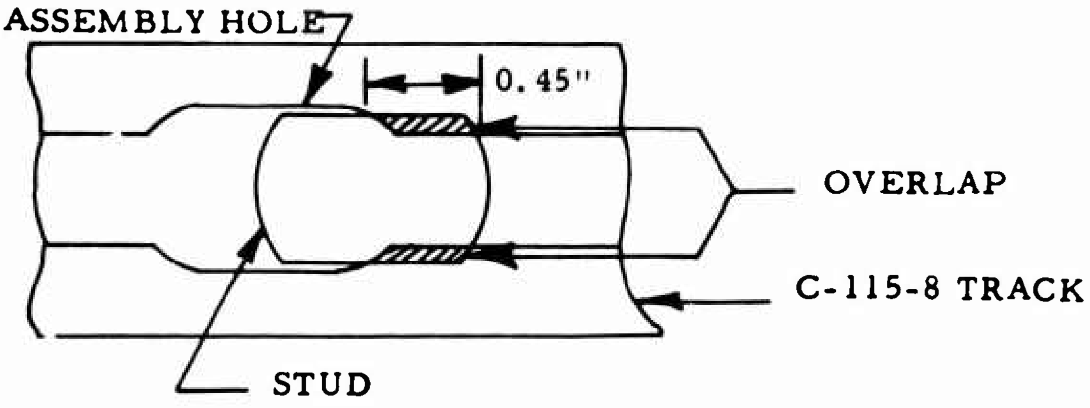
$$\text{M.S.} = \frac{10,000}{8,580} - 1 = \underline{.17.}$$

---

* An occupant utilizing the full-up position is not likely to exceed 190 pounds. The seat is assumed to weigh 30 pounds in accordance with specifications.

The track shear strength is least when the seat is in the full-forward position, locating the stud partially in the assembly hole.

The bending stresses of the track flanges are not critical and are not considered along with the shear stresses.



The length of track section in direct shear is then 0.9 inch, with an average thickness of .16 inch. Thus, the shear strength is

$$F_{ult} = F_{su} \times A_s = (45,000)(.9)(.16) = 6480 \text{ lb.}$$

The margin of safety for 30G is thus negative;

$$M.S. = \frac{6480}{8580} - 1 = \underline{-.24}$$

or failure is indicated at 23G. For all other positions, the shear stressed area of the track is more than twice as great, or

$$F_{ult} > 12,960 \text{ lb}$$

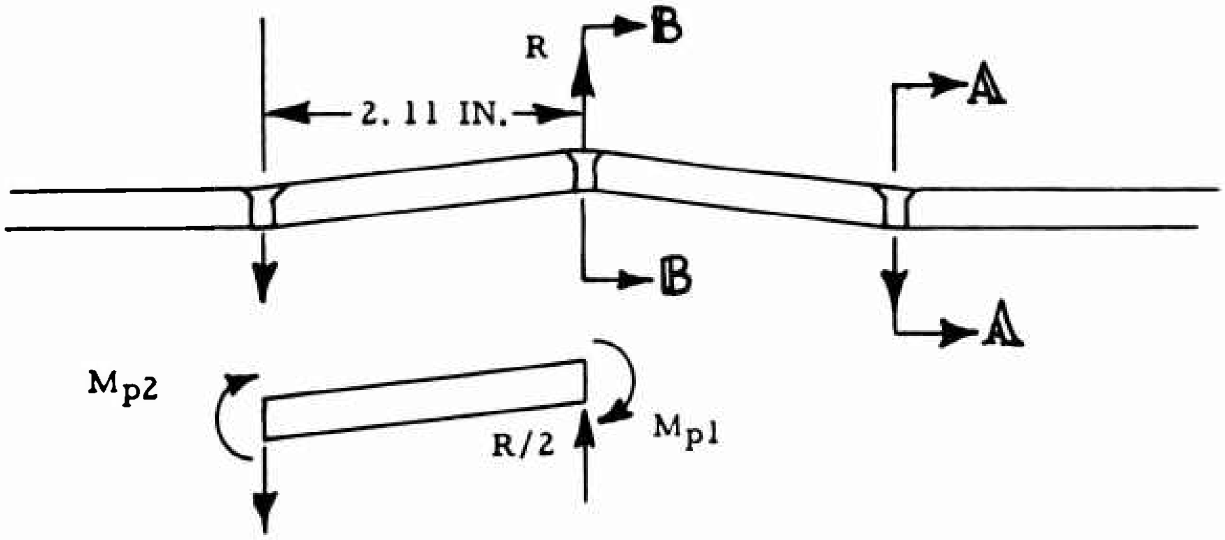
$$M.S. > \frac{12,960}{8,580} - 1 = \underline{.51.}$$

It is recommended that the most forward seat position be blocked off as shown in HC-1-13 to eliminate the weak section of the track.

In analyzing the existing track tie-down strength, two positions of the rear track stud are considered. First, if the stud is adjacent to a pair of .19-inch-diameter AN3 bolts whose ultimate tensile strength is given as 2210 pounds each, then the tie-down load R_2 is limited by

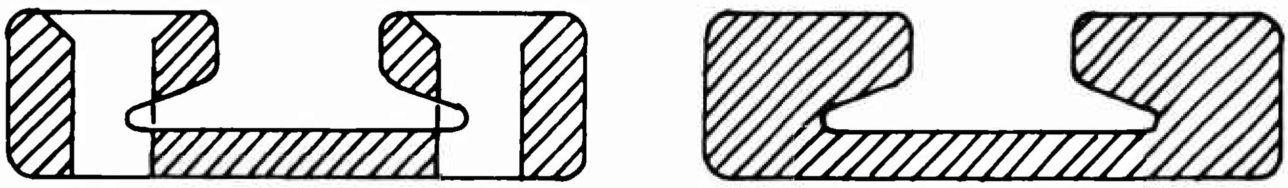
$$R_{ult} = 2\ (2210) = 4420 \text{ lb.}$$

This corresponds to a deceleration of 15.5G (as R_2 = 8580 lb corresponds to 30G). Secondly, if the stud lies midway between two pairs of tie-down screws, a plastic failure mechanism would appear as shown below:



(EXISTING)

The "plastic hinge" moments M_{p2} and M_{p1} would correspond to yield hinges in a track section reduced by screw holes and a section without screw holes respectively.



SECTION AA
WITH SCREW HOLES

SECTION BB
COMPLETE SECTION

The plastic moments are computed to be (using 70 Ksi as an equivalent yield stress)

$$M_{p1} = 2450 \text{ in.-lb} \qquad M_{p2} = 1120 \text{ in.-lb.}$$

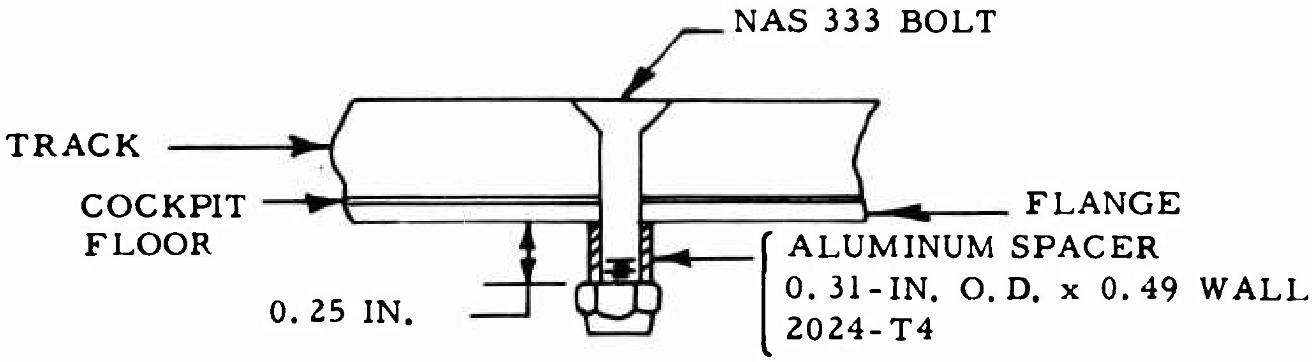
From equilibrium,

$$\frac{R}{2}(2.11) = M_{p1} + M_{p2}$$

$$R = 3380 \text{ lb}$$

This corresponds to a deceleration of approximately 12G.

The recommended modification to the track tie-down, as shown in drawing HC-1-13, involves the addition of NAS 333 screws spaced .75 inch on centers over the region in which the aft stud can exert upward force. Aluminum spacers would be inserted between the nut and underside of the floor beam flange for each bolt as shown below:



The spacers have a cross-sectional area of .04 square inch and are of 2024-T3 aluminum rated at 44-ksi average yield strength and 67-ksi average ultimate. Thus, plastic deformation would occur at an average load of

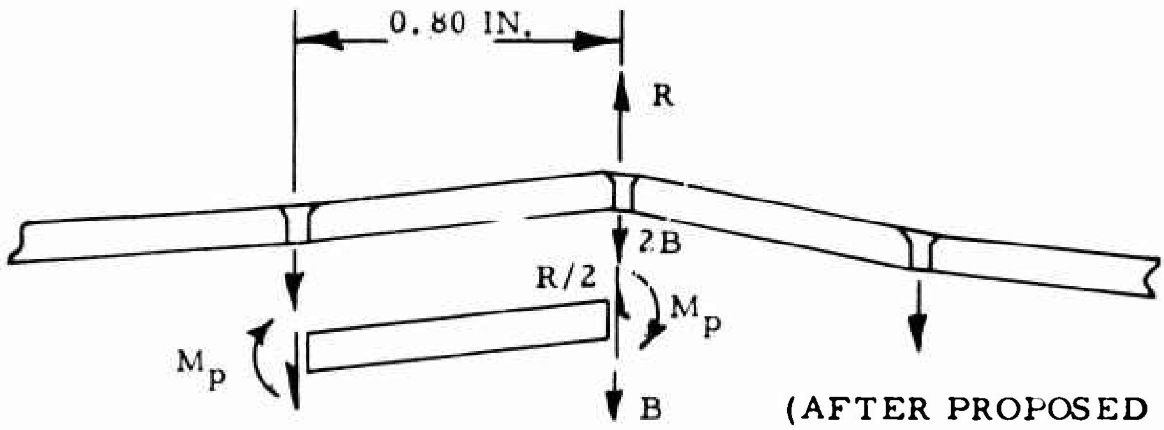
$$F_y = (44,000)(.04) = 1760 \text{ lb},$$

while the ultimate load on the spacer is F_{ult}

$$F_{ult} = (67,000)(.04) = 2680 \text{ lb}$$

Since it is noted that the ultimate tensile strength of NAS 333 bolts is 2700 pounds, the spacers would deform plastically prior to bolt failure but would sustain the bolt load ultimately. This action would permit the upward stud force to be transmitted to more than one pair of bolts.

Consider the critical position with the stud directly under one pair of bolts:



From equilibrium,

$$\left(\frac{R}{2} - B\right) .80 = 2M_p$$

or

$$R = 5.00\ M_p + 2B.$$

As computed earlier, M_p = 1120 in.-lb, and B = 2700 lb; hence

$$R = 11,000 \text{ lb},$$

and, for 30G deceleration,

$$M.S. = \frac{11,000}{8,580} - 1 = \underline{.28.}$$

Attachment of Seat Track Underfloor Beams (114S-1108)

The aft stud reaction force, R_2, is transmitted to the subfloor seat track support beam by the NAS-333 tie-down screws which are attached directly to the flanges of the beam cap tee section. Seven .19-inch-diameter rivets are assumed to be effective in transmitting the force from the cap angle to the .04-inch-thick web (114S1108-11). The rivet bearing strength is critical; for .19-inch-diameter rivets in .040 (2024-T4) web, the ultimate bearing strength is 764 pounds each.

Hence, for seven rivets,

$$F = (7)(764) = 5350 \text{ lb},$$

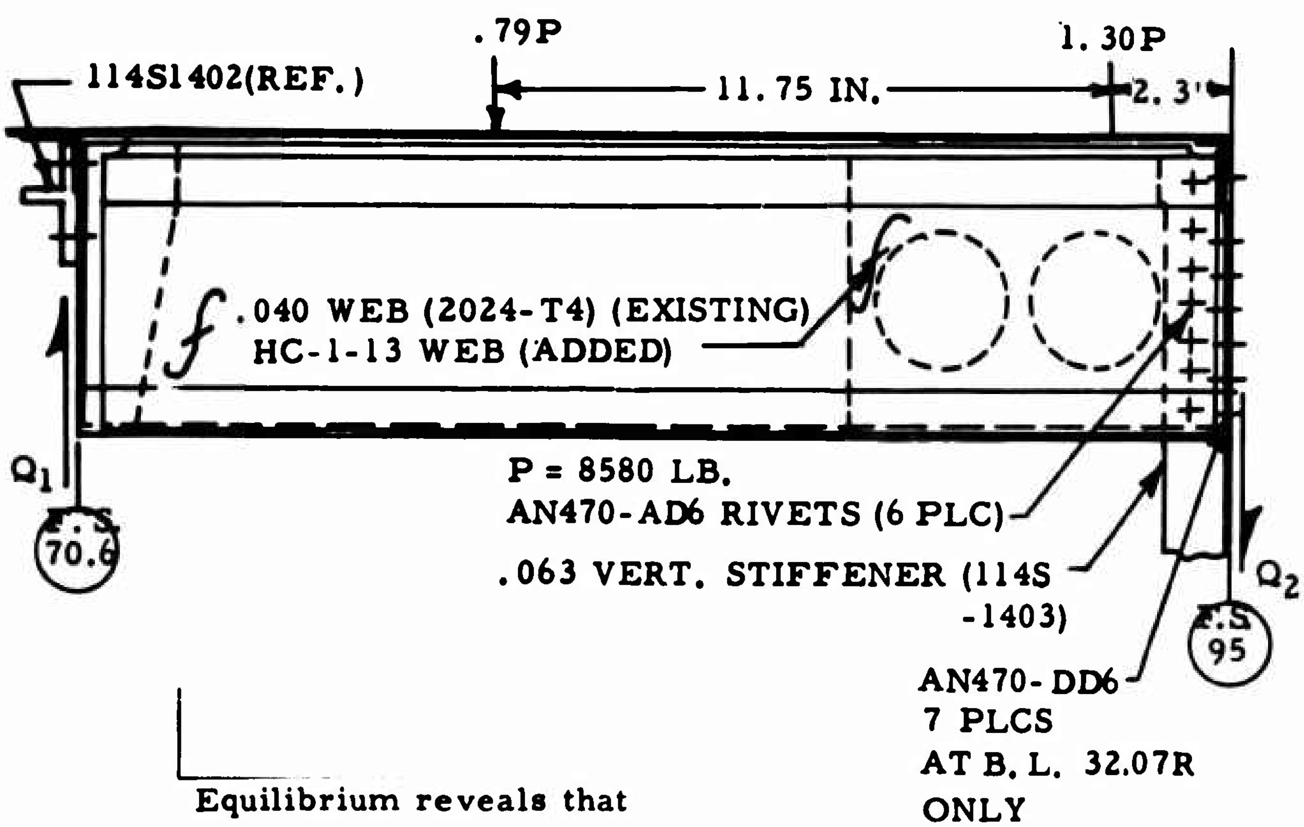
which corresponds to 19G deceleration (based upon R_2 = 8580 for 30G).

The addition of an .040 doubler plate, as shown in HC-1-13, would place the same seven rivets in double shear, increasing the ultimate load by a factor of two.

Hence,

$$M.S. = \frac{10,700}{8,580} - 1 = \underline{.25.}$$

After transferring the seat track loads into the underfloor beam, the attachment of the beam itself to the underfloor structure must be considered. All four track beams are attached by angles to the F.S. 95 bulkhead and the F.S. 70.62 transverse underfloor beam (114S1402). The beam at B.L. 32.07 on the right side is critical, since the shear attachment to the F.S. 95 bulkhead is lowest at this location. The critical load on this beam occurs with a combination of a forward and a left-hand lateral load, as this combination applies the highest couple load which must be sustained at F.S. 70.62 and F.S. 95. This loading diagram of the beam is illustrated as follows:



Equilibrium reveals that

$\underline{Q_2 = 7250 \text{ lb.}}$

The proposed attachment of the beam at F.S. 95, at all four beams, is made by six .19-inch-diameter rivets in double shear between the .04 inch webs (ref. HC-1-13). The double shear strength of the rivets in the .063 inch leg of the vertical stiffener is 1410 pounds, and the total strength in six rivets x 1410 = 8460 pounds.

$$M.S. = \frac{8460}{7250} - 1 = \underline{.17.}$$

The attachment of all the vertical stiffeners on the forward side of the F.S. 95 web (to which the underfloor beam fastens) is adequate with the exception of the B.L. 32.07 R stiffener (114S1403-29), which extends from W.L. -17 to W.L. -22.4. The stiffener is attached with seven .156-inch-diameter rivets, which are insufficient. It is recommended that these be replaced with .19-inch-diameter (AN470DD6) rivets at 1180 pounds each in the .063 thick material, which can sustain a total load of seven rivets x 1180 pounds = 8260 pounds.

Thus,

$$M.S. = \frac{8260}{7250} - 1 = \underline{.14}$$

In summary, theoretical calculations reveal that a deceleration of the order of 12G (at a load angle of 26.5^{o} with the longitudinal axis) would be sufficient to fail the existing seat. With the proposed modifications incorporated, the components considered would sustain a seat load of 30G; but it is recommended that a static load test be conducted to prove this analysis for the entire seat.

TROOP LAP-BELT RESTRAINT

The ultimate lap-belt tensile strength is employed to establish the design load for the lap-belt attachments. For an intermediate fitting, to which two belts are fastened, the attachment load is calculated to be 5000 pounds (reference 8) while the forward end attachments are designed for 2500 pounds. The aft, single belt attachment, however, is assumed to take 3800 pounds, since a forward inertia force coupled with belt friction action would increase the load on this attachment (reference 8).

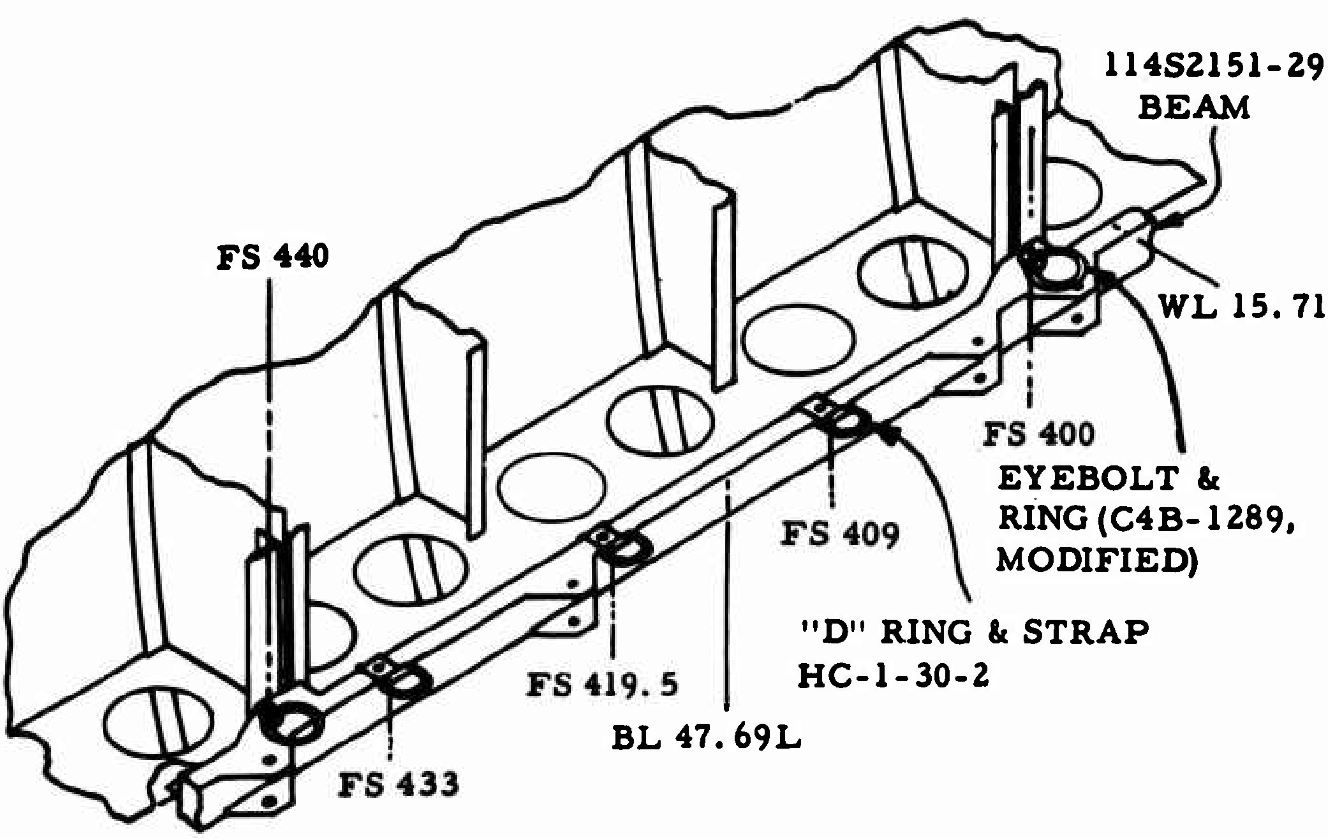
From anthropometric studies (reference 9), the lap belt is found to make an angle of approximately 24^{o} with the horizontal. To obtain the most severe loading on intermediate fittings, a purely lateral inertia force is assumed.

Applying these loads to the existing installation, excessive torsion occurs in the seat support rail (114S-2151-29). The ACA-2128 eyebolt attachment strength also is insufficient. Consequently, modifications as shown in HC-1-30 are recommended.

In the modified installation, three different local attachment arrangements are employed; these are analyzed separately:

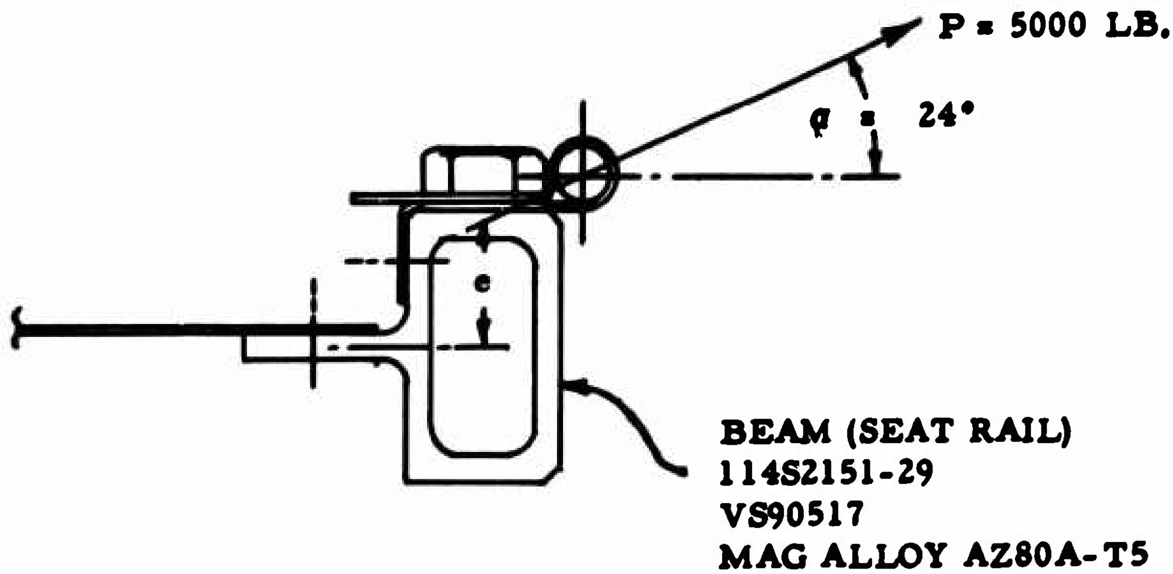
1. Attachments are made directly to fuselage formers by means of eye bolts.
2. For belt attachment points between formers, a strap is used to secure a "D" ring to the seat support rail.
3. For the end portions of the seat rail (where no intercostal web is present), a similar strap arrangement transmits the load back to a skin stringer.

A typical portion of the installation is shown in the sketch below:



Seat Support Rail

The support rail is subjected to both torsion and bending:



1. Torsion

Applied torque = Pe cos α

For the 24-inch spacing attachments, an example of the critical condition would be represented by the attachments at F.S. 409 and F.S. 433. The maximum internal torque is found from a standard indeterminant analysis to be 1.05 times the applied torque.

For a thin-walled section, the shearing stress is approximately (reference 11, page 176, article 10) as follows:

$$\tau = \frac{T}{2tA} = \frac{1.05\,(5000)\,(.5)\cos 24^{\circ}}{2tA}$$

where T = internal torque

t = minimum wall thickness

A = area enclosed by median boundary.

For

$P = 5000, \quad e = .5'' \quad A = 0.77 \text{ sq. in.} \quad t = .105 \text{ in}$

$\tau = \underline{14,800 \text{ psi.}}$

For AZ80A-T5, the ultimate shear stress is 20,000 psi; therefore,

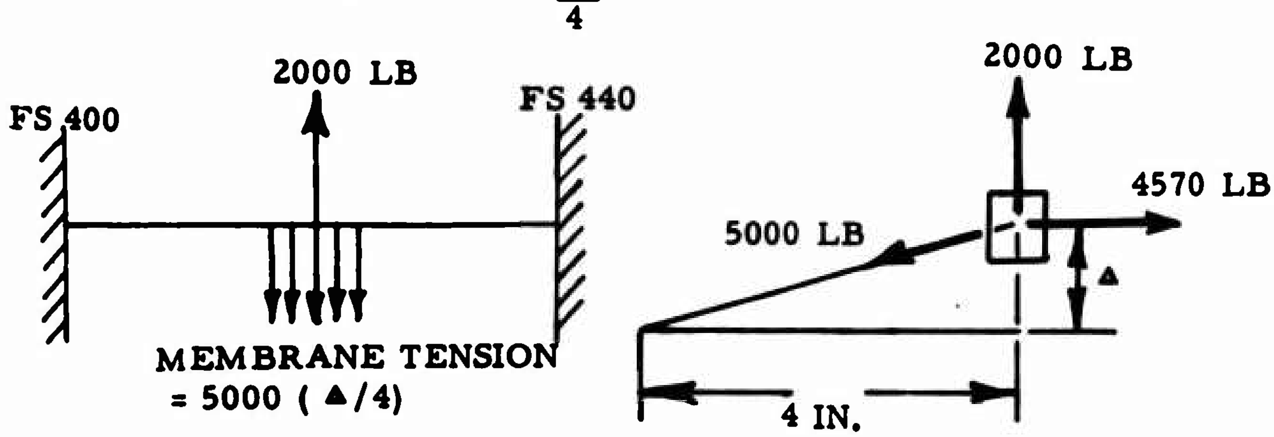
$$M.S. = \frac{20,000}{14,800} - 1 = \underline{.35.}$$

2. Bending

Bending in the lateral direction is restrained by the intercostal web.

Bending in the vertical direction may take place to a limited extent. The vertical component of the applied force at the attachment is reduced by the downward vertical component of the intercostal membrane tension near the attachment.

For the 20-inch attachment spacing, the applied load is located approximately mid-span with a vertical component of 2000 pounds. The vertical component of intercostal tension is from geometry as shown below equal to 5000 $\frac{\Delta}{4}$.



For a load P at the center of a fixed end beam, the deflection is

$$\Delta = \frac{PL^3}{192\ EI}$$

where

$$P = 2000 - 5000\left(\frac{\Delta}{4}\right).$$

Hence,

$$\Delta = \frac{2000L^3}{192EI} - \frac{5000L^3}{192EI}\left(\frac{\Delta}{4}\right).$$

Letting δ denote the deflection due to the 2000 pounds alone, we have

$$\Delta = \delta - \frac{5}{8}\delta A$$

or

$$\Delta = \frac{\delta}{1 + \frac{5}{8}}.$$

For $EI = .494 \times 10^6$ lb-in.^{2}, $\delta = 1.35$ in. and hence $\Delta = .54\delta$.

Since deflection is proportional to load, the net vertical force, P, is then

$$P = (.54)(2000) = 1080 \text{ lb}$$

and the consequent maximum bending moment is

$$M = \frac{PL}{8} = 2370 \text{ in.-lb},$$

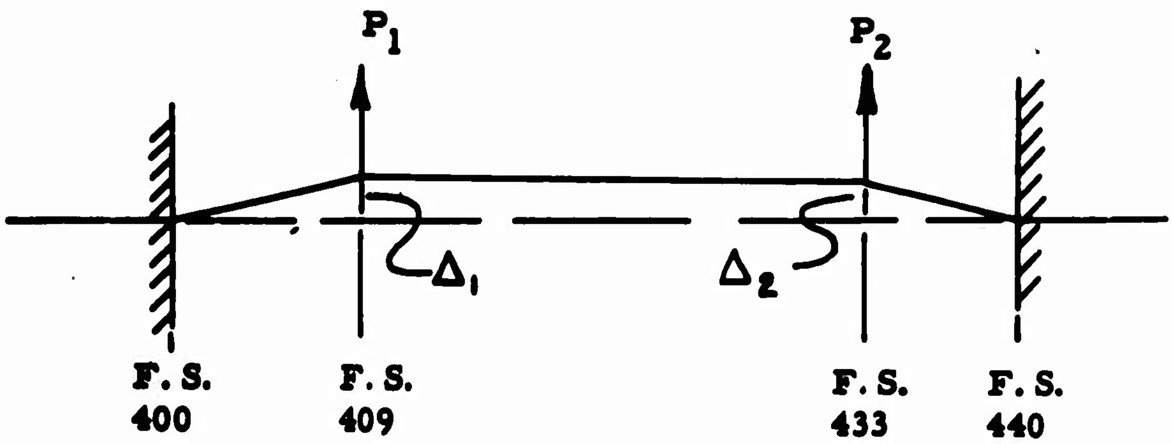
from which the stress is

$$\sigma_B = \frac{Mc}{I} = 20,200 \text{ psi}.$$

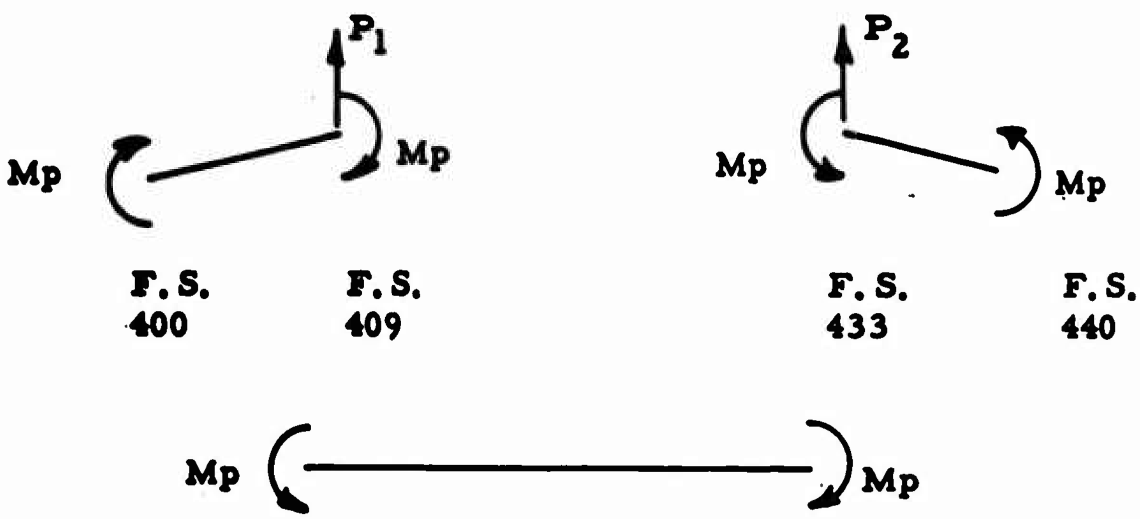
For AZ80A-T5, the ultimate tensile stress is 47,000 psi and the margin of safety is high.

For the 24-inch spacing indicated in the following sketch (which is the most critical bending load for the seat rail), the bending stresses based upon elastic analysis would exceed the yield stress of the material; hence, limit analysis (references 5 and 6) would be appropriate.

Assuming that "yield hinges" form at the ends and at the attachments, we may calculate limit loads P_1 and P_2 shown as follows:



Free-body diagrams:



$P_1 = \frac{2Mp}{9}$ $\qquad$ $P_2 = \frac{2Mp}{7}$

For the seat rail cross-section, the plastic moment is calculated to be

$M_p = .162 \; F_{ty}$,

and for an equivalent yield stress, F_{ty}, of 35,000 psi, we obtain

$M_p = 5670$ in.-lb.

Hence,

$P_1 = 1260$ lb, $\qquad$ $P_2 = 1620$ lb.

Since the actual applied vertical loads at these attachments are 2000 pounds each, vertical components of intercostal membrane tension must then supply the differences of 740 pounds and 380 pounds at F.S. 409 and F.S. 433, respectively. If, as in the previous discussion, the intercostal web is taken as 4 inches wide and the membrane tension is 5000 pounds, the required deflections are approximately

$$\Delta_1 = .6 \text{ inch at station 409}$$

$$\Delta_2 = .3 \text{ inch at station 433.}$$

A deflection of .6 inch at station 409 would correspond to a hypothetical strain of .0085 inch per inch (employing elastic analysis). This indicates that limit load strains are well below the elongation of 4 per cent given for AZ80A-T5 material.

Attachment of Eyebolt and Ring to Fuselage Formers

The eyebolt selected has at least as great a strength as the standard AN 45 bolt, which has an ultimate strength of 5290 pounds. However, as the attachment load may have components not in line with the eyebolt, a reduced distance from the eye to the shank portion is considered desirable; hence, this governed the selection of the special eyebolt rather than a standard AN 45 eyebolt.

The bolt ring is assumed to deform in plastic bending under the application of the load. The ultimate load would then be governed by the shear strength of twice the cross-sectional area of the ring. Thus,

$$P_{ult} = 2AF_{su}.$$

For 125 ksi , 4130 steel, the ultimate shear strength is 82 ksi.

Hence,

$$P_{ult} = 2\,(.049)\,(82,000) = 8000 \text{ lb}$$

$$M.S. = \frac{8000}{5000} - 1 = \underline{\underline{.60.}}$$

The eyebolt is secured to the former through a leg of the former cap angle. Assuming a .56-inch-diameter washer behind the eyebolt nut, the "coining" failure load may be expressed in terms of the thickness, t, of the flange through which the bolt passes:

$$P_{ult} = \pi(.56)tF_{su}.$$

For 7075-T6 aluminum alloy, F_{su} is 43,000 psi; hence, for the smallest flange thickness encountered (.070-inch at F.S. 260),

$$P_{ult} = \underline{5300 \text{ lb}}$$

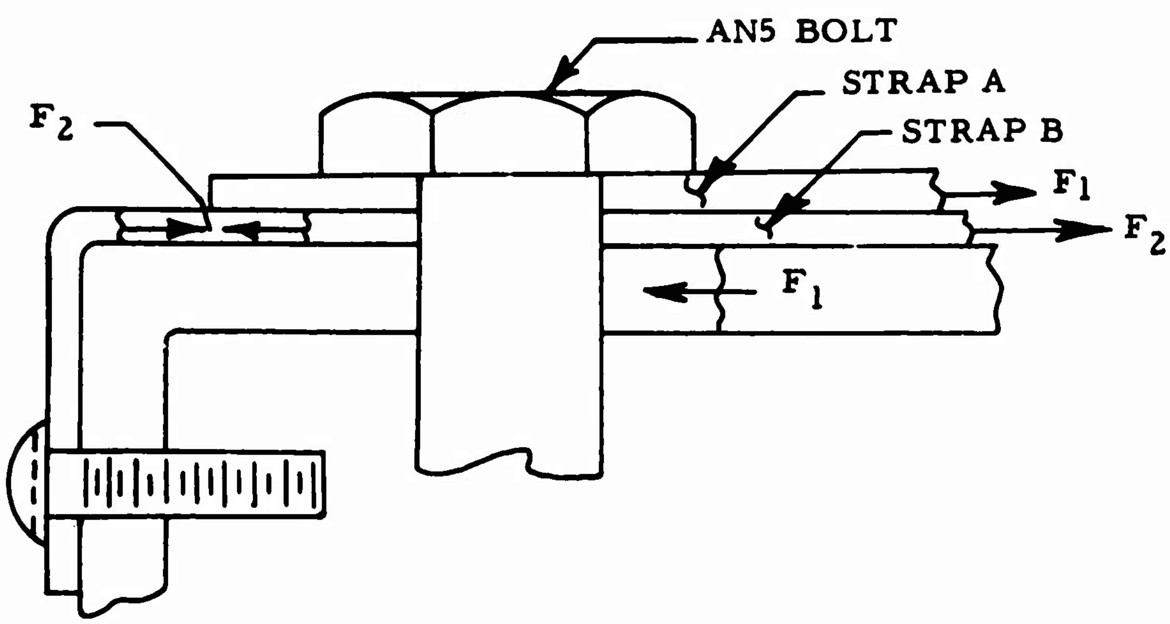
$$M.S. = \frac{5300}{5000} - 1 = \underline{\underline{.06.}}$$

The cap angle at each former is riveted to the former web by rivets spaced approximately .7-inch on centers. A span of 6.3 inches, therefore, corresponds to ten rivets. Assuming the ten rivets to be effective at 574 pounds per rivet in transmitting the attachment load to the web, the ultimate load is 5740 pounds or

$$M.S. = \frac{5740}{5000} - 1 = \underline{\underline{.15.}}$$

Attachment to Seat Rail by Means of Tie Strap and "D" Ring

The applied load is transmitted to the seat support rail in part through the .31-inch bolt and partly through the strap that folds over the back of the rail as shown.



The force F_1 is transmitted through strap A (HC-1-30) to the bolt and then to the rail in bearing. The bearing strength of the 4130 steel strap and the AZ80A magnesium rail should be considered.

For the steel strap,

$$F_1 = AF_{bru} = (.04)(.31)(287,000) = 4000 \text{ lb.}$$

For the magnesium rail,

$$F_1 = AF_{bru} = (.125)(.31)(60,000) = 2325 \text{ lb.}$$

Hence, the magnesium governs the strength of Strap A.

The tensile capacity of Strap B is (using net area at bolt hole)

$$F_z = A\,F_{tu} = (.04)(.8 - .31)(150,000)$$

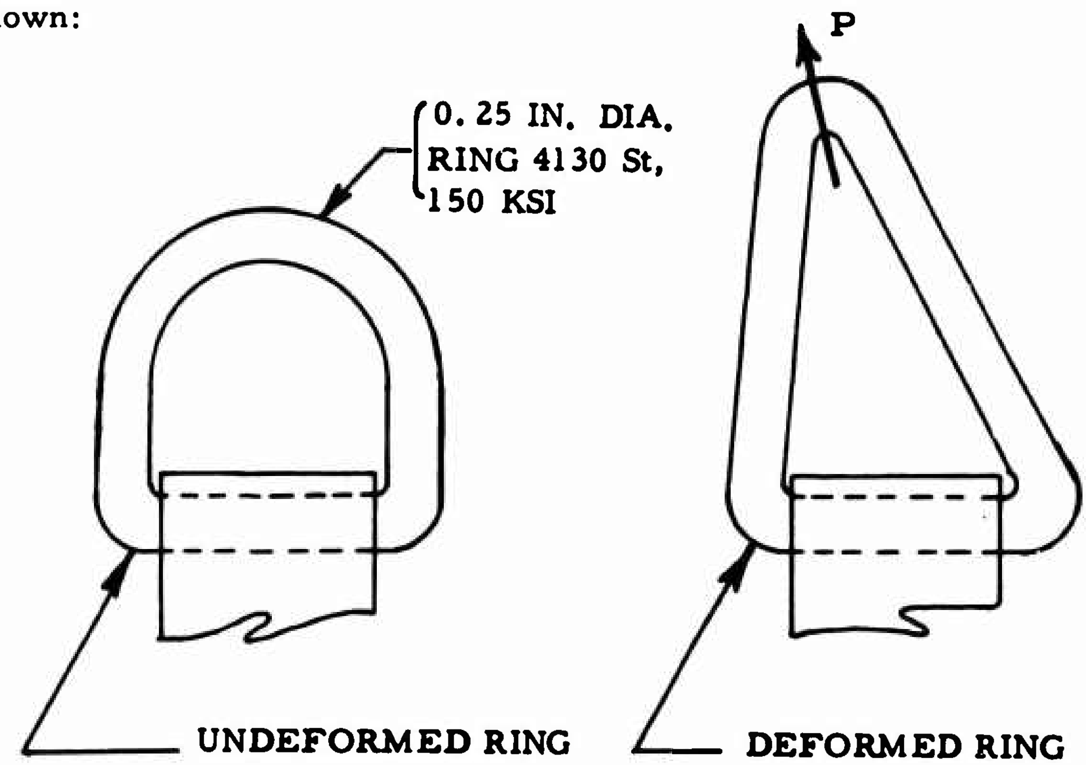
$$F_z = \underline{2940 \text{ lb.}}$$

Thus, the total load is 2340 lb + 2940 = 5280 lb; hence,

$$\text{M.S.} = \frac{5280}{5000} - 1 = \underline{.06.}$$

Attachment Ring

The ultimate load on the "D" ring is assumed to deform it plastically as shown:



In the deformed configuration, the tensile capacity in each leg of the triangle would be

$$T = A F_{tu} = (.049)(150,000) = 7350 \text{ lb},$$

which provides for a high margin of safety.

The total shear force on the two cross sections adjacent to the strap is

$$P_{ult} = 2 A F_{su};$$

and for ultimate shear strength $F_{su} = 95$ ksi ,

$$P_{ult} = 2(.049)(95,000) = 9300 \text{ lb}.$$

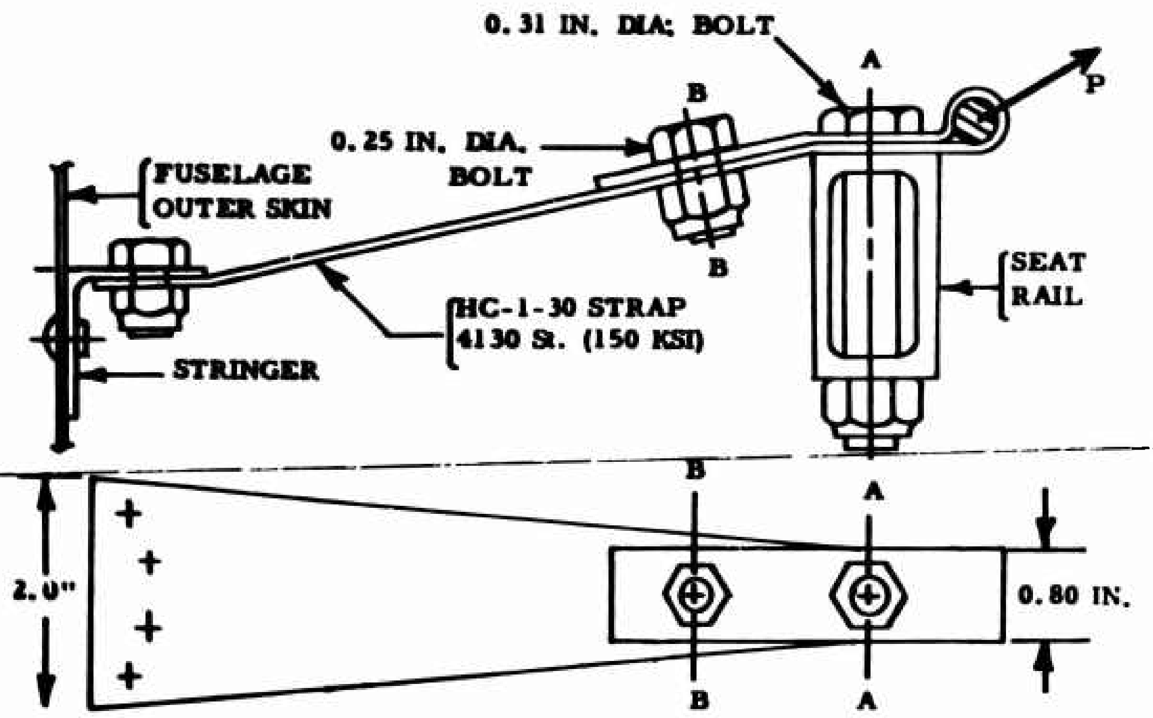
Hence,

$$M.S. = \frac{9300}{5000} - 1 = \underline{.86.}$$

Although it is recognized that the shear forces on each of the two areas may not be equal, in view of the high margin of safety the attachment is considered safe.

Special Attachments at Stations 145 and 457.

Where no intercostal web exists, the attachment must be tied back to the outer skin stringer as shown.



In strap tension across the reduced area of section A, the load capacity for the lower strap is

$$P_1 = (.04)\,(.8 - .31)\,F_{tu} = (.04)\,(.49)\,(150{,}000) = 2940 \text{ lb.}$$

The capacity of the upper strap is governed by the bearing strength of the strap at the .25-inch-diameter bolt at section B.

$$P_2 = (.04)\,(.25)\,F_{bru} = (.04)\,(.25)\,(287{,}000) = 2870 \text{ lb}$$

The total strap load is thus

$$P_{ult} = P_1 + P_2 = \underline{5810 \text{ lb.}}$$

$$M.S. = \frac{5810}{5000} - 1 = \underline{\underline{.16.}}$$

At the outboard end, the strap widens to accommodate four .156-inch-diameter AN470D5 rivets at F.S. 145 (for the single belt load of 2500 pounds) and four .19-inch-diameter aluminum lockbolts at F.S. 457. Thus,

$$\text{for F.S. 145, M.S.} = \frac{4 \text{ rivets} \times 675 \text{ lb}}{2500} - 1 = \underline{.08};$$

$$\text{for F.S. 457, M.S.} = \frac{4 \text{ bolts} \times 1260 \text{ lb}}{5000} - 1 = \underline{.01}.$$

SUPPLEMENT

RESTRAINT SYSTEM MODIFICATION DRAWINGS - CH-47 AIRCRAFT

(Published under separate cover)

The restraint system modification drawings included in the supplement to this report are listed as follows:

HC-1-10	-	This is a master drawing which locates and identifies the modifications.
HC-1-11 thru HC-1-14 and HC-1-19 thru HC-1-21 and HC-1-25	-	These drawings cover cockpit modifications.
HC-1-15 thru HC-1-18 and HC-1-22 thru HC-1-24	-	These drawings cover the troop commander's restraint harness modifications.
HC-1-30 (3 sheets)	-	This drawing covers the modification of the troop lap belt attachment fittings.
AvCIR-10 and AvCIR-15	-	These drawings describe the single tiedown strap which is applicable to all Army aircraft.

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U. S. Army Transportation School	5
U. S. Army Quartermaster School	1
Deputy Chief of Staff for Logistics, D/A	4
U. S. Army Transportation Center and Fort Eustis	4
U. S. Army Infantry Center	2
U. S. Army Aviation Maintenance Center	5
U. S. Army Materiel Command Aviation Field Office	2
U. S. Army Armor Board	1
U. S. Army Aviation Test Board	1
U. S. Army Arctic Test Center	1
U. S. Army Airborne, Electronics and Special Warfare Board	1
U. S. Army Board for Aviation Accident Research	5
Bureau of Safety, Civil Aeronautics Board	2
U. S. Army Aviation Test Activity, Edwards AFB	1
Air Force Systems Command, Andrews AFB	1
~~Air Force Systems Command, Wright-Patterson AFB~~	~~1~~
Wright Development Division, Wright-Patterson AFB	4
Air University Library, Maxwell AFB	1
Air Force Flight Test Center, Edwards AFB	2
U. S. Air Force Directorate of Flight Safety Research, Norton AFB	1

U. S. Army Representative, U. S. Naval Aviation Safety Center	1
Chief of Naval Operations	1
Bureau of Naval Weapons	4
U. S. Naval Aviation Safety Center	2
Naval Air Test Center	2
Naval Air Materiel Center	3
Naval Air Development Center	1
Helicopter Utility Squadron TWO, Lakehurst	2
David Taylor Model Basin	1
Hq, U. S. Marine Corps	2
Marine Corps Landing Force Development Center	1
Marine Corps Educational Center	1
Hq, U. S. Coast Guard	1
NASA-LRC, Langley Station	4
Lewis Research Center, NASA	1
Manned Spacecraft Center, NASA	1
NASA Representative, Scientific and Technical Information Facility	2
National Aviation Facilities Experimental Center	3
Aviation Research and Development Services, FAA	2
Bureau of Flight Standards, FAA	2
Bureau of Aviation Medicine, FAA	2
Civil Aeromedical Research Institute, FAA	2
Director of Army Aviation, ODCSOPS	3
Aviation Safety Division, ODCSOPS	2
Director of Safety, ODCSPER	1
The Surgeon General	5
Bureau of Medicine and Surgery	3
Armed Forces Institute of Pathology	2
National Library of Medicine	3
National Institutes of Health	2
U. S. Public Health Service	2
Human Resources Research Office	2
Defense Documentation Center	10
U. S. Government Printing Office	1

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